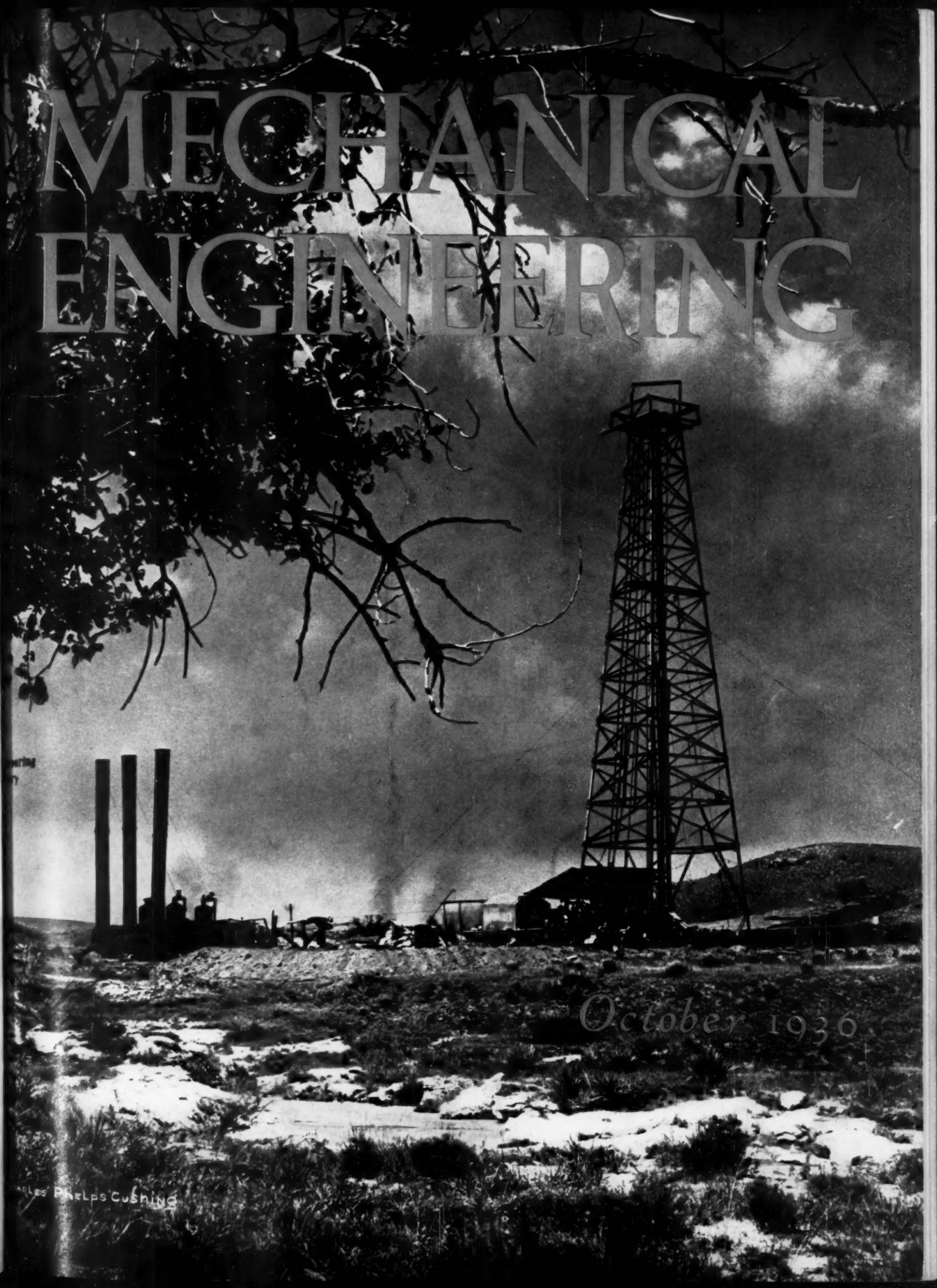
MECHANICAL
ENGINEERING
October 1936
Charles Phelps Cushing

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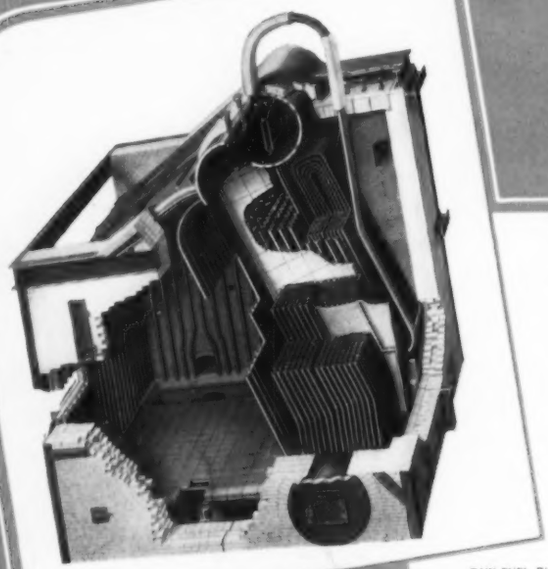

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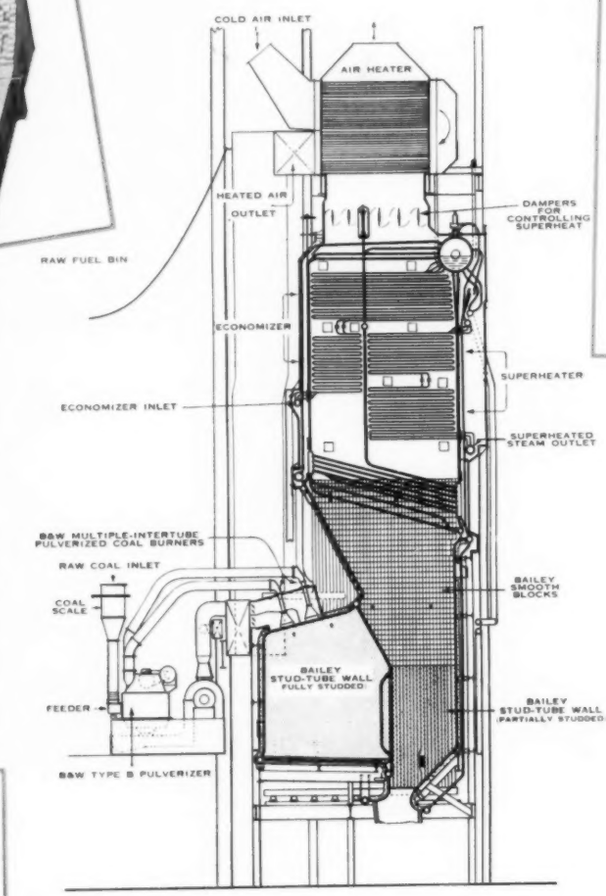

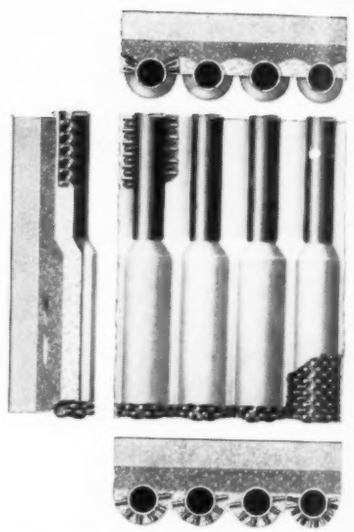

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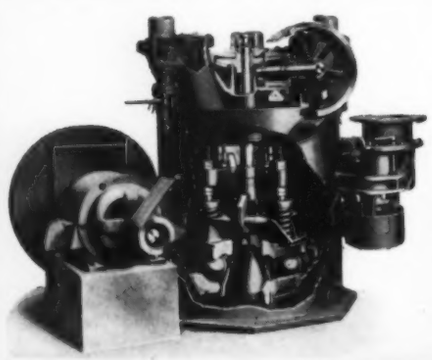

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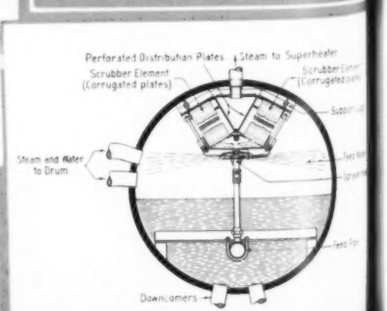

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MECHANICAL ENGINEERING

Published by The American Society of Mechanical Engineers

VOLUME 58 NUMBER 10

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Published monthly by The American Society of Mechanical Engineers. Publication office at 20th and Northampton Streets, Easton, Pa. Editorial and Advertising departments at the headquarters of the Society, 29 West Thirty-Ninth Street, New York, N. Y. Cable address, "Dynamic," New York. Price 60 cents a copy, $5.00 a year; to members and affiliates, 50 cents a copy, $4.00 a year. Postage to Canada, 75 cents additional, to foreign countries, $1.50 additional. Changes of address must be received at Society headquarters two weeks before they are to be effective on the mailing list. Please send old as well as new address.... By-Law: The Society shall not be responsible for statements or opinions advanced in papers or ....printed in its publications (B2, Par. 3)....Entered as second-class matter at the Post Office at Easton, Pa., under the Act of March 3, 1879....Acceptance for mailing at special rate of postage provided for in section 1103, Act of October 3, 1917, authorized on January 17, 1921....Copyrighted, 1936, by The American Society of Mechanical Engineers.Member of the Audit Bureau of Circulations.

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(*For program of A.S.M.E. Welding Practice Symposium, Cleveland, Ohio, October 22–23, see page 672 of this issue*)

VOLUME 58
No. 10

MECHANICAL ENGINEERING

OCTOBER
1936

GEORGE A. STETSON, *Editor*

A.S.M.E. News

SEVERAL years ago, as an economy measure, publication of the *A.S.M.E. News* was suspended, and certain material it customarily contained was transferred to a news section of MECHANICAL ENGINEERING, called, for lack of a better name, "What's Going On." Obviously, no economy could be expected if MECHANICAL ENGINEERING were to assume the complete function of the *News*, and hence only notices required by the rules of the Society to be printed—announcements of meetings, and similar items—were featured. Society publicity of its own affairs to its own members was reduced to a minimum.

For more than a year the Committee on Publications has been giving thought to the need for more Society news and has canvassed many plans, most of which involve expenditures that cannot be financed at this time. However, the Committee has recently felt justified in recommending that greater emphasis be placed on Society news and has decided to make a start in this direction by a process of gradual expansion that will involve, for the present, little additional expense.

To this end the news section, formerly known as "What's Going On," has been renamed "A.S.M.E. News," and changes in typography have been adopted. While these changes involve more space they will call the reader's attention more emphatically to the various items. As time goes on and conditions permit, an orderly development of this section may be expected if interest in it and the demand for the service it renders warrant expansion and improvement.

Student Branch Bulletin

IN SPITE of the fact that much publicity has been given to the student branches of The American Society of Mechanical Engineers, it will come as a great surprise to many older members to learn that there are 115 of these groups of undergraduates, and that during the academic year, 1935–1936, the student-branch members totaled 3793. Since the graduation of the class of 1935, 725 student members became junior members through the procedure set up by the recently revised constitution, by-laws, and rules. Surely this is impressive testimony of the fact that the Society draws its potential strength from engineering colleges, and that the student-branch movement is one about which more members of the Society should be regularly informed.

A step in this direction is being taken this month by incorporating in the "A.S.M.E. News," the news section of MECHANICAL ENGINEERING, the former *Student Branch Bulletin*. Members are invited to turn to these pages every month and see for themselves what the Committee on Relations With Colleges is doing to discharge its important responsibility.

Probably few members of the Society ever saw the *Student Branch Bulletin*. Established several years ago at the request of the Committee on Relations With Colleges as an aid to its work, this four-page bulletin was published monthly during the academic year and distributed to the student members. Several editorial plans of attack were tried, and responsibility for editorial content was passed from one group to another until, a year ago, an editorial board of junior members in the Metropolitan area took over the task. During all this time the *Bulletin* was constantly on the minds of the Committee on Relations With Colleges and the Committee on Publications, and late this spring both committees came independently to the opinion that it should be incorporated with MECHANICAL ENGINEERING.

The objective in making this change is twofold. First, it is thought that the time has come to keep members of the Society more closely in touch with the student branches and their activities, particularly since membership grades of the Society have been revised to include that of student member. Second, it is hoped that by this recognition of the work of the student branches the student members will feel themselves to be more closely identified with the Society and will come to have a more intimate interest in it and in MECHANICAL ENGINEERING.

Because of the variety of subjects of which it treats MECHANICAL ENGINEERING has a wide appeal to young men who are making the acquaintance of this profession of diversified and extensive interests. Like a majority of junior members, most student members are uncertain of the particular branch of engineering in which their major interests will lie. It behooves them, therefore, to be sensitive to developments in all branches and to maintain a lively and intelligent familiarity with whatever any group in the profession is doing. On the one hand the articles of broad significance that give depth and understanding to a man's thinking should not be neglected in a world in which the engineer is emerging as a person of increasing importance with enlarged responsibilities to society. On the other, technical papers, some of which may tax the minds of men far removed from textbooks and fundamental theory, provide a vitalizing intellectual diet to those recently exposed to

the more scientific interpretation of engineering problems that is typical of the best trends in engineering education. If MECHANICAL ENGINEERING can catch the keen interest of minds undergoing formal training and assist those minds during the years of intellectual let-down that frequently follow graduation to retain their vigor and development, it will perform a useful service.

Help Industry's Cause

A GROWING awareness of the extraordinary hostility of uninformed persons and reactionary demagogs has been quickening the engineering profession and industry in general to a defense of its rôle in modern life. Respecters of facts by training and modest and indifferent to undeserved criticism by nature, engineers have gone steadily forward in the development of their works and the improvement of industrial technique without sufficient attention to the need for enlisting the enthusiastic support of other social and economic groups and for educating their critics to their objectives and accomplishments. But a growing tide of adverse criticism and counter propaganda, swollen by the effects of the depression, social consciousness, and changing political dogmas all over the world, has borne in on the minds of many engineers and industrialists the need for answering their traducers and presenting the undeniable facts to the uninformed and the misled.

Notable among recent champions of what engineers and industrialists have contributed to our present-day standard of living and manner of life are the editors of *Factory* who have devoted the August issue of that magazine to an effective presentation of what industry means to America. In this remarkable issue the mistake of boring the reader with statistics and long-winded explanations and apologies has been successfully avoided by presenting facts in a pictorial style that emphasizes the essentials with dramatic simplicity and conviction. Nor have the editors stopped at this point, for in a couple of pages at the end they suggest a number of ways in which the material they have put into such attractive and understandable form may be effectively used for the education of those who do not customarily review this magazine. *Factory* has done its part, and done it amazingly well. But it remains for the great bulk of its readers to see to it that the material so carefully assembled is brought to the attention of the public, and in particular to the thousands of workers in their plants.

Factory's August issue is reminiscent of the instructive charts presenting facts and statistics, that the National Industrial Conference Board has been issuing for many years. It also serves to call to mind efforts that are being made by other organizations to combat the false notions and loose thinking that have characterized recent attacks on our industrial society. Not many weeks ago the National Association of Manufacturers exhibited a "canned" lecture with a series of pictures that may be obtained for educational use in factories and similar places where an audience of workmen can be assembled. By means of lively conversation a retired worker who has a surprising number of useful but devastating statistics at his tongue's end is able to convince his son and a young but misinformed workman that machines do not put men out of work permanently, but provide a host of goods and services we all are eager to demand for ourselves and at the same time open up possibilities for employment in many new fields. The "lecture," the pictures, and the apparatus for presentation at factory meetings are easily obtainable.

In this connection mention may also be made to two recent pamphlets issued by the Machinery and Allied Products Institute, "Ten Facts on Technology and Employment," and "More Facts on Technology and Employment." Similarly, the National Machine Tool Builders' Association has issued a bulletin, "More Goods for More People," which presents another aspect of the place machines have come to occupy in our economy. Nor should it be forgotten that practically every trade magazine has been alive to the need for counteracting disruptive propaganda by publishing hundreds of articles which provide arguments and statistics for the industrialist who is alive to the necessity of setting straight the thinking of his friends and employees on this important subject.

Certain industrialists in positions of importance have also recognized the importance of this form of public education by basing the themes of their addresses and popular articles on lines of providing constructive information. The times call for such a recognition of the gravity of the situation in which industry finds itself. Already in other countries drastic and painful changes in political organization and control have stepped in to do the job that American industrialists are at last electing to do for themselves under a democratic form of social organization that has been responsible in the past for the rapid progress of the standard of living in this country. The American Society of Mechanical Engineers has been fortunate in having among its members industrialists and engineers of the type of Ralph E. Flanders and C. F. Hirshfeld who have served nobly in the task of coordinating the thinking of engineers and extending its constructive results to the public in general. And MECHANICAL ENGINEERING has opened its pages to articles dealing with these subjects, mindful of the factors at work in the world to destroy, or misdirect, or retard the sure progress of the industrial trend of modern society.

There are few who would claim that industry has had none but beneficial effects on men and their social organizations. Grave problems confront us, and the gravity of these problems makes possible a hearing for the demagog and the reactionary. Individuals can do little by themselves; but if every engineer would assist, intelligently, and with patience and calm reason, in presenting the facts and convincing others of their significance, a strong countercurrent of informed opinion and sound judgment would unquestionably be set up. MECHANICAL ENGINEERING urges all its readers to join in this educational work.

FIG. 1 CHARLES AUGUSTIN COULOMB, 1736–1806
(From "Grosse Naturforschen," by Philipp Leonard, J. F. Lehmans Verlag, Munich, 1930.)

The Life and Works of CHARLES AUGUSTIN COULOMB

By S. C. HOLLISTER

CORNELL UNIVERSITY, ITHACA, N. Y.

CHARLES AUGUSTIN COULOMB was born in 1736. He came into a world curiously alive to a growing science, patronized by monarchs, and idolized by the literate public. Truly the stage for science was completely set and functioning at the time of his birth.

Probably Galileo, more than any other one man, was responsible for the beginning of this great era, although his contemporary, René Descartes, will share the distinction of strengthening the philosophical foundations upon which the new structure was to be built. During their early lifetime Viéta removed algebra from the realm of rhetoric to that of symbolic operation. Napier and Briggs invented the logarithms. But these were merely the tools of the scientist. The liberalization of science itself was more dramatically portrayed in the struggles between Galileo and his Church and was carried on by the philosophical pursuits of the eccentric Descartes.

Galileo died in 1642, and in the same year Isaac Newton came into the world. Contemporary with Newton were Christian Huygens in Holland, Leibnitz in Germany, and the elder Bernoulli in Switzerland. The profound respect in which these men were held in their own and in other countries aided materially in quickening the organization of scientific societies which were made possible through the rising tide of freedom of thought and speech which the philosophers of the time were fostering. Monarchs were capitalizing the situation through a program of founding scientific academies and patronizing scientists and philosophers generally.

The Accademia del Cimento was founded by Leopold de' Medici at Florence in 1657 at the instigation of Viviani, the geometrician, pupil of Galileo. It fostered experimental

An address delivered on the Bicentenary of the birth of Coulomb, at the National Meeting of the Applied Mechanics Division, Pittsburgh, Pa., June 13, 1936, of THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS.

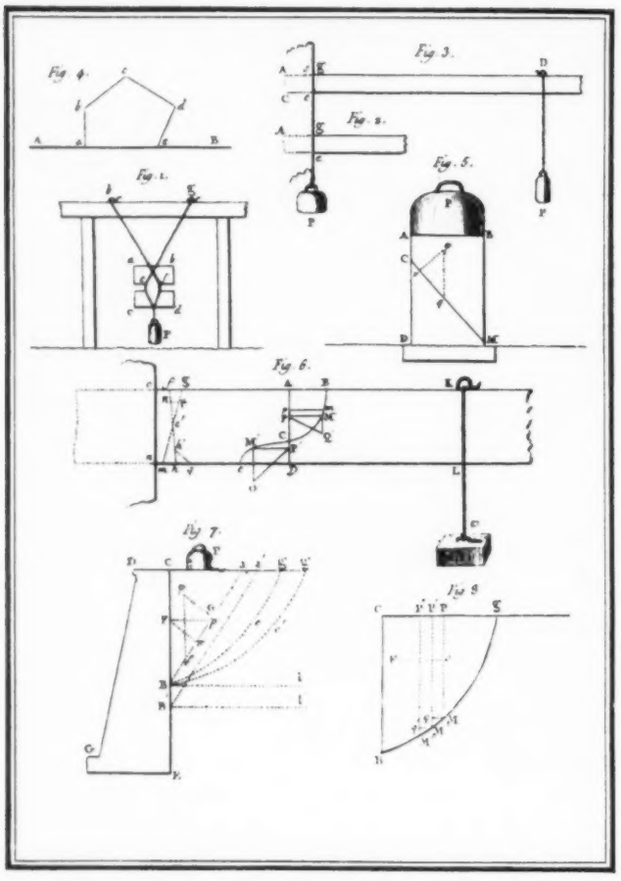

FIG. 2 FACSIMILE OF PLATE FROM PAPER ON RUPTURE OF BRITTLE MATERIALS, STRESSES IN A BEAM, AND PRESSURES OF COHESION AND GRANULAR EARTHS

science in contrast to the deductive science of the quadrivium. In 1662 the Royal Society of London was chartered, in the early days of the reign of Charles II, who restored the monarchy after the régimé of the Great Commoner.

The Academy of Sciences in Paris was founded in 1666 through a royal grant of Louis XIV and was an outgrowth of a private society which had been meeting for some thirty years.

In Germany the Royal Scientific Society was founded by Frederick I on a plan proposed by Leibnitz, who was its first president. Peter the Great also desired such an organization in Russia, and, with the advice of Leibnitz, drew a plan for it in 1724. Catherine I carried out his plan in the following year and she herself was present at its first meeting in August, 1726, when Professor Bülffinger delivered an oration upon "The Determination of Magnetic Variations and Longitude." The fifteen members of the Academy were pensioned as professors in the various branches of science and literature.

Membership in all of these societies was small and highly selective. Their patrons vied with one another in the eminence of their memberships. Problems were propounded and prizes posted. Smaller nations and many cities, on a less pretentious scale, organized similar academies and societies. Perhaps at no time before nor since was science so highly elevated not only in the public mind, but in the minds of statesmen and rulers as well.

In such a setting was Coulomb born. The struggle with theology was over and the entrenchment of free scientific thought was great enough to withstand the political and social upheaval he was to witness during his lifetime. How strong this scientific tide was may be judged by the mention of Coulomb's contemporaries: Joseph Black, James Watt, Joseph Priestly, and Henry Cavendish in England; Galvani and Volta in Italy; Daniel Bernoulli in Switzerland; Euler in Russia and Germany; and Laplace, Lagrange, Monge, Lavoisier, and d'Alembert in France.

Coulomb was born of a family which had distinguished itself in the magistracy of Montpellier. His family had for generations been charged with the care of the fountains of France. He was educated in Paris and acquired a decided taste for mathematics. Circumstances prevented him from devoting himself entirely to that branch of science and he entered the military corps of engineers. He was assigned to duty on the Island of Martinique, where he remained nine years engaged in the construction of fortifications and other military works. Many of his fellow officers died with fever, and in broken health he returned to Paris some time near 1770.

Coulomb's first paper was read before the Academy of Science in the spring of 1773 (*a*).[1] In this same spring, in England, Thomas Young was born. In December of the same year Boston staged its celebrated Tea Party. This memoir, which Coulomb himself indicates was prepared while he was still in Martinique, and probably when he was not far from thirty years of age, is entitled "An Essay on the Application of the Rules of Maximum and Minimum to Some Problems of Statics Relative to Architecture." It is not only remarkable in its simplicity and clarity of analysis, but on the strength of this single paper Coulomb will always hold a position in the first rank in the field of mechanics.

Before proceeding with a discussion of this first paper, it is important to review the background of mechanical analysis at this time. Admitting that Newton's fluxions gained little or no headway on the Continent, mathematical analysis in France was based on the calculus of Leibnitz. By 1700 it is said that only Newton, Leibnitz, the elder Bernoulli, and L'Hopital possessed any useful knowledge of the calculus. Its great development came largely at the hands of the Bernoullis and Euler prior to 1760.

In the mechanics of the beam, Galileo, in his famous book of 1638 (1),[2] attempted to determine the modulus of rupture of a rectangular cantilever beam, but his analysis was faulty as regards the internal stresses which he assumed to be tensile forces distributed over the entire cross section and acting as though concentrated at the center of the section, with the compression concentrated at one edge. In 1684 Mariotte, in his "Traité du mouvement des eaux" (2), pointed out the existence of tension on one face and compression on the other. He assumed the stresses concentrated at one third of the distance from the neutral plane toward each face, which neutral plane he arbitrarily located at the center of the cross section. Robert Hooke had, in 1678 (3), declared stress proportional to strain in an elastic member, but this principle had not found its way into the mechanics of the beam, except in some remarks by Leibnitz (4).

There was no theory of elastic breakdown or theory of failure in brittle materials. No experimental test data on the strength and behavior of materials were to appear for nearly another fifty years.

It was against this background of imperfect theory, paucity of test data, and an awakening power of analysis, that Coulomb prepared his paper on the Island of Martinique.

In the introduction Coulomb said:

[1] Letters in parentheses refer to list of Coulomb's works at end of paper.

[2] Numbers in parentheses refer to Bibliography at end of paper.

This memoir, composed some years ago, was at first designed for my own individual use on the different works in which I was engaged in my profession. If I dare to present it to this Academy it is because it welcomes with kindness the most feeble attempt when it has a useful objective. Besides, the Sciences are monuments consecrated to the public good. Each citizen ought to contribute to them according to his talents. While great men, carried to the summit of the edifice, mark out and lift up the upper stories, ordinary artisans scattered through the lower stories or hidden in the obscurity of the foundations should seek only to perfect that which cleverer hands have created.

This paper is divided into four parts: The first treats of the carrying capacity of a brittle material in simple tension or compression and states the criterion of failure on a diagonal plane. This serves also to initiate the maximum-shear theory in elastic breakdown, although Coulomb treats shear as a kind of friction. The second part of the paper for the first time locates correctly the neutral surface of a beam; points out the presence of shear on the cross section, which, Coulomb states, gives the oblique tensile and compressive resultants, now called principal stresses; states the hypothesis that a plane section remains plane after bending (this had been used in 1705 by James Bernoulli); and sets stress proportional to the distance from the neutral axis.

The third part of the paper deals for the first time with earth pressures against retaining walls. He conceives the pressure as arising from the tendency of a wedge of earth to exceed, on some inclined plane, its internal friction, and to slide forward against the wall. He determines that wedge which will exert a *maximum* pressure against the wall. He then discusses at length the effect of cohesion, and shows that with it present, the soil will rupture along a curved surface. Nowhere does he consider the angle of internal friction to equal the angle of surface repose. He treats the soil as a cohesive fluid, and thus lays the foundation for the study of viscous flow.

The fourth part of the paper is a discussion of the stability of masonry arches. He first shows how to find the curvature of the pressure line (hence the arch axis) for a given set of continuous loads; and comments that his result is identical with that of Euler (5) who sought the shape of a chain acted upon by any forces whatever. He then discusses the safe range of variation of the position of the pressure line, and establishes a practical method for the determination of the proper inclination of the voussoir faces.

The paper displays its author's easy facility in mathematics; but more outstanding is the clarity of insight into the actions treated, based upon observations of behavior in practical construction. The paper won for Coulomb the title of correspondent to the Academy of Science.

About this time Coulomb discovered a method of accomplishing all sorts of underwater construction (*c*). He proposed using a diving bell from which the water would be entirely excluded by compressed air forced into the working chamber—a method common today in tunneling and other deep-water excavations. He also gave an account of his observations on the types of windmill which seemed to him most successful in practice, taking into account the force of the wind, the effect of friction, and the loss produced by it (*e*).

During Coulomb's stay in Martinique and after his return to France, he conducted experiments to evaluate the amount of work men could do daily according to the different ways they used their strength. The purpose of this study was to show men how they might reduce their fatigue when obliged to work like simple machines. The results were presented in a memoir to the Academy in 1775, but were not published until twenty-five years later (*q*).

In 1779 Coulomb and van Swinden were awarded the prize

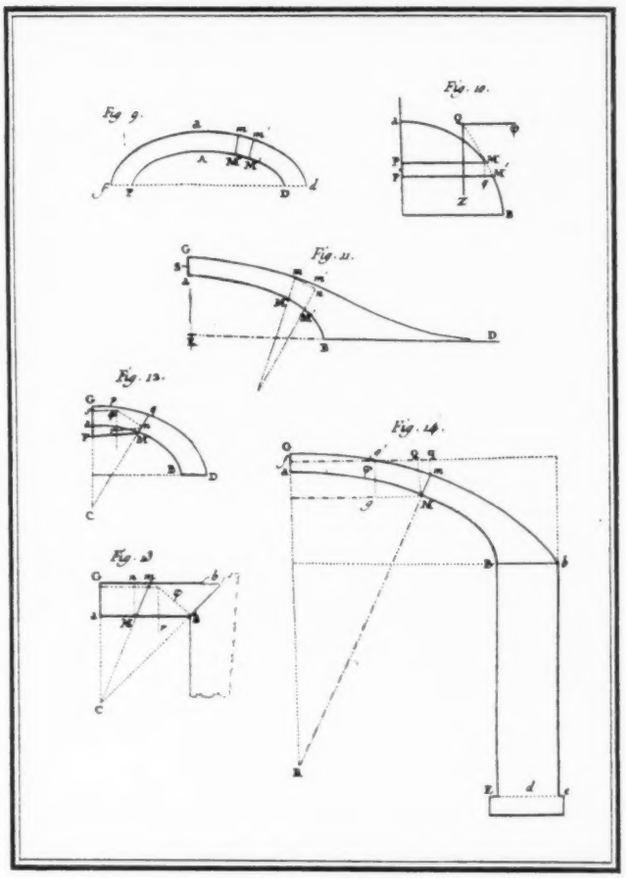

FIG. 3 PLATE ACCOMPANYING COULOMB'S DISCUSSION OF STRESSES IN A MASONRY ARCH

of the Academy for the best way to construct a compass (*b*). Two years later Coulomb won the prize on the theory of friction in simple machines (*d*).

Amontons (6), Bülffinger (7), and Parent (8) had published some research on the same subject; but experiments made in a small way, in a physics laboratory, were not enough to estimate the friction of machines designed to carry enormous weights. Coulomb devised a heavy table carrying a slab of the material to be tested, which could at will be loaded with very considerable weights, and which would allow him to vary the experiments, to calculate the stresses and the losses, to observe the friction of different bodies slipping on one another in different directions, dry or coated with greasy substances, with an acquired speed, or at the instant they start up from a state of rest more or less prolonged.

By these tests Coulomb confirmed the earlier opinion that the friction between plane surfaces varies with the pressure and is independent of the area of contact, although this point was still controversial. He determined the coefficient of friction for many practical combinations of materials; measured static as well as dynamic friction and investigated the effect of time upon the former and velocity upon the latter; and measured the friction of axles and of pivots. Later, he extended his work on the friction of pivots (*o*), by testing them against glass and other materials and with various angles of bevel.

In 1781 Coulomb obtained permission to perform his military service in Paris. The Academy was eager to admit him as a member. He began seriously the study of torsion, and upon the results obtained turned to his research in electricity

and magnetism, upon which his fame rests as a physicist.

While making experiments on the compass Coulomb employed a needle suspended by a thread or fine wire. One of his critics suggested that the twisting of this thread or wire induced a restraining effect on the free motion of the needle. The nature of torsion, at this time, was not understood. Coulomb outlined a machine which he thought would be capable of studying torsion with high precision.

To appreciate justly the services he has rendered the science of physics and the advantages of his method, let us give a rapid glance at the condition of the science in different eras.

The ancients know of physics only its name. It is enough to convince one to read, if one can, the numerous treatises of Aristotle, on physics in general as well as on the sky, on generation and corruption, and on meteors. In all these writings what do we remark but endless dissertations on infinity, time, principles, and elements? What fruit can one reap from this obscure and unintelligible metaphysics?

What can one learn in a shorter treatise where Plutarch has rendered to Greek philosophers the bad service to assemble in a narrower frame all their opinions or rather their dreams as if he had wanted by this comparison to make them more ridiculous? What do we see in it, if it is not that, contented to have observed with idle gaze a few phenomena which gave them matter upon which to exercise their imaginations, they did not know how to invent any of those ingenious machines used to interrogate nature; so that with the exception of a few bright truths spread through the writings of Archimedes, without his inventions and those of some mechanic-geometricians from Alexandria (and among others, Heron, whose name is still borne by a curious machine used in physics laboratories) one would be quite at a loss to find in their writings any lines to carry on into modern treatises, where their names can be mentioned only because of their errors.

We see the cause of the ancients' small progress in physics; they treated it only as metaphysicists.

Why were they more successful in astronomy? Because early, they felt the necessity to apply to it suitable instruments, observation and calculation. The fortunate application of geometry to one of the most important branches of physics, indicated the road to follow to improve equally all the others. It is in fact, the one that Galileo took, at the renaissance of Letters and Sciences. It is in geometry that he found the new and ingenious means of measuring the fall of bodies.

The pendulum, the barometer, the pneumatic machine and the prism have enlarged the field of experience, the book of mathematics placed science on its true basis, and we feel that it could improve itself only as much as we succeed in carrying into its most obscure parts, the twin lights of experiment and calculation.

's Gravesande (9) tried to compose a complete course of physics-mathematics, but magnetism and electricity could not enter his plan. Electricity was just dawning and magnetism was too little advanced.

Æpinus (10) was the first man to submit them to analysis; he tried chiefly to explain the known effects; his progress was still a little uncertain; he neglected too often to verify through experiment all the results of his computation.

It is in throwing light upon one from the other, in combining them cleverly, that Coulomb was led to the unknown truths with which he enriched the science of physics (11).

He noted that magnetic as well as electric attraction was strong when the bodies were close together, but diminished rapidly even at relatively small distances. To measure the strength of this attraction it was necessary to oppose it by some small force which could be accurately measured and yet would respond to the particular attraction. With the knowledge he possessed of the torsion of small wires, Coulomb saw the possibility of applying the torsional pendulum as a means

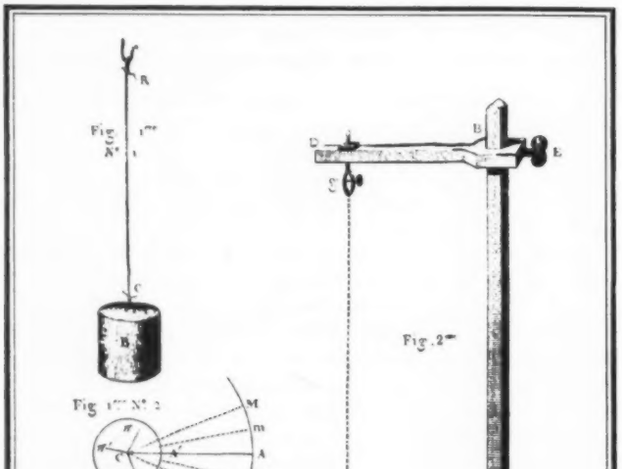

FIG. 4 PLATE SHOWING APPARATUS FOR TORSION EXPERIMENTS

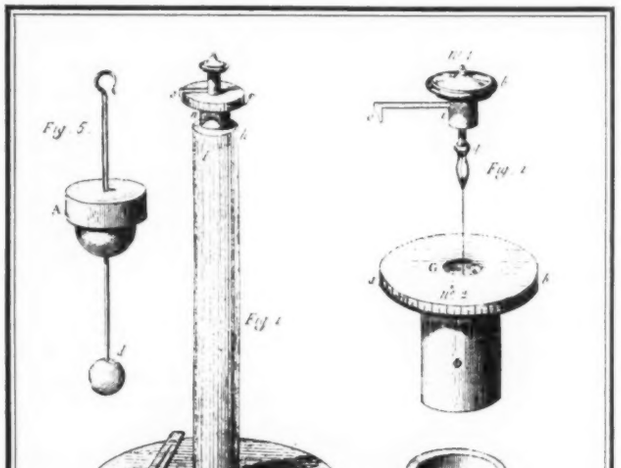

FIG. 5 STUDY OF ATTRACTIONS

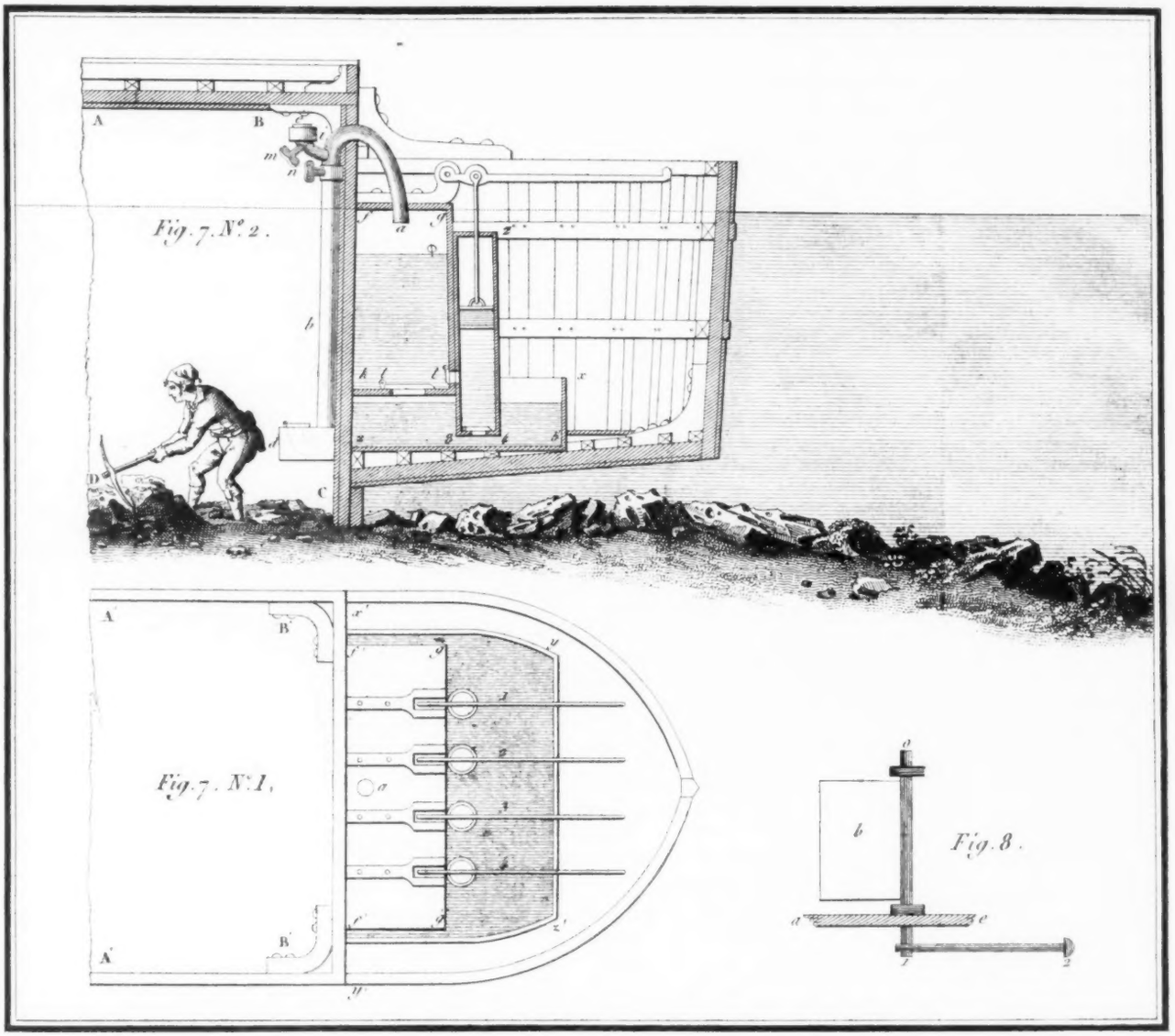

FIG. 6 COULOMB'S SCHEME FOR A PNEUMATIC CAISSON, 1778

of measuring these attractions. His torsional research (*f*) stands as a beautiful example of simplicity and directness of method. He established by experiment all the fundamental laws of torsion and torsional oscillation. He had shown that the torsional resistance is proportionate to the angle of twist.

From that time Coulomb possessed the desired instrument for his physical measurements. He constructed torsional pendulums so sensitive that they would make a complete revolution with a force of $^1/_{70,000}$ of a grain, and would rotate through an angle of 90 degrees when a rubbed bar of sealing wax was held at a distance of one yeard. By so simple a means he was able to demonstrate the law which had remained unestablished by experiment; he showed most convincingly that attractions and repulsions were inversely proportional to the square of the distances. Though many had foreseen it, this law was immediately admitted by all physicists. Aepinus, though often using another principle in his calculation, had thought this law the most probable, but had been unable to find any way in which to demonstrate it; this privilege was reserved for Coulomb. During the ten years Coulomb lived in Paris, he published his seven great memoirs on electricity and magnetism (*h–n*). The impression these works made upon physicists of the time can be appreciated when we recall the naming of a standard unit of electricity, "the coulomb."

Thus far we have considered Coulomb only as a distinguished engineer and physicist. The man in him was no less commendable. He possessed exquisite common sense. The correctness and severity of the principles which had dominated his mathematical research was equally to be found in his moral philosophy and conduct.

On one occasion he was sent by the Secretary of the Navy as commissary to the King, to survey some canal projects; he used all his energies on this occasion to thwart ruinous plans. The grateful province wished to bestow upon him a gift commensurate with their gratitude, but were unable to persuade him to accept any other form of reward than one whose merit would be in reminding him several times a day of the esteem in which he was held by them for the services he had rendered.

The Revolution came. Many of his colleagues in the Academy fled for their lives, others were put to death by the

guillotine. Coulomb resigned all his positions. Among them was the supervision of relief maps and the general administration of the fountains of France. This latter position had been hereditary in his family, and through Coulomb would have passed down to his son and grandsons.

Deprived of everything, he tried to gather together the remains of his wealth, of which he could save but a very small amount; he hoped to find some consolation at the Academy and in the continuation of his work, but the Academy was abolished. He was still a member of the commission of weights and measures; he was now dismissed. Soon after, obliged to leave Paris because of the new law driving out all the nobles, he retired, followed by his friend Borda (12), to a country place he owned near Blois.

In this solitude, in the bosom of his family, with the consolation of friendships Coulomb hardly changed his manner of living. He could continue his meditating, which he extended to new things. Vegetation attracted his penetrating gaze. Some trees he had cut down furnished him with new observations on the movement of sap (*p*). He began researches on plants. We have found in his manuscripts some fragments of these which make us wish to find the rest of them.

He was called back from exile to continue the work relative to the development of the metric system. He was in a hurry to rejoin his wife and his children, and to resume the care of the little property which was their only resource. He came back to live in Paris only at the creation of the Institute in 1795. His failing health made it necessary to be near the medical help which he had refused for a long time, on account of his excessively nervous temperament and very quick disposition, and a temper from which he alone suffered because of the constant efforts he made to master it.

Appointed one of the general inspectors of studies, although he could consider this favor as a necessary compensation after so many losses and although he was as worthy as any one of this important post because of his knowledge of all branches of public education, he questioned for some time whether to accept it or not; we feared for him the fatigue which could be detrimental to his health, and a long absence which would interrupt work which no one else could do. Also he had been educating a son who already was responding very nicely to his care, and he would have to entrust him to other hands. He accepted, however, and Madame Coulomb became his inseparable companion on all his travels. Thanks to her tender and intelligent care, the traveling had not all the consequence which we had feared.

M. Coulomb gave himself to his new functions, with the zeal and exactitude he carried everywhere. His grave and severe face would soften for the young pupils who recalled a tender joy to his paternal heart. He was like a father talking to his children: he helped their weakness, encouraged their timidity; he loved to find in their young looks and dispositions the forecast and the germ of talents which would be some day useful to the Fatherland.

It is for those who have seen him in his private life to give testimony to his charm and ease. A good husband, a good brother, a good father and good friend, an upright man and a devoted citizen, he practiced all the virtues without boasting and without effort. Fastidious, severe to himself, indulgent to others, his manners united a practiced ease with the gravity which formed his character, but which did not exclude a calm and sweet gaity, that of a soul at peace with itself. Noble and generous in all his affairs, his own interests were the least of his worries. Modest and far from pretentius, he knew to repulse unjust aggressions with as much strength as dignity.

In fact, this last trait of character found few occasions to manifest itself. On the only one which came to our knowledge and which the Institute probably has not forgotten, the opponent did not intend to attack Coulomb and admitted that he was wrong. No man has enjoyed a more general esteem. He has seen his doctrines accepted and taught by the most distinguished professors. They were pleased to do him justice, his merits and his success have never made him a single enemy, nor occasioned any envy. He lacked only good health. His health had been giving us much anxiety for a long time; to a grave and alarming infirmity which he himself regarded as an imminent cause of death, was added last summer a slow fever which mastered him. In the exhausted state to which he was reduced, he could not retain the least nourishment. The medical resources administered by friendly hands were equally powerless either to ease his pain or to revive his strength. He died the 23rd of August 1806, leaving scarcely any heritage to his two sons but a very respected name, the example of all his virtue, and the memory of the brilliant services he had rendered to science (13).

Such was the man who was born to this world two hundred years ago, June 14, 1736.

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Synthetic RESINS *in* VARNISHES *for* WOOD PROTECTION

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CONTRIBUTIONS made by synthetic chemistry during the past ten to twenty years have revolutionized many old industries and ushered in many new ones. Chemical processes have displaced older natural ones; synthetic products hatched in the fertile mind of the chemist have superseded many products formerly occurring only in Nature. The engineers of the country particularly have been in a place of vantage to observe industry, after it became alert to changing conditions, adopt the new chemistry and thus modernize products or processes. And engineers have also been in a position to witness unprogressive industries, oblivious to the need for research, suddenly awake to find their processes obsolete or their products displaced.

EARLY HISTORY OF VARNISHES

The paint and varnish industry is a notable example of revolutionary change during the past few years, for from early antiquity up to about the early 1920's the slow-drying oil-fossil-resin varnish was the basis of most industrial finishing. A varnish contained essentially the following ingredients: A drying oil, such as linseed, obtained from flax seed or in more recent years tung oil pressed from the nuts of the tung tree of China; a fossil resin, such as kauri from New Zealand, copals from East India, Africa, or South America, or rosin from the Southern pine tree of our country. Catalytic driers such as litharge or umber were cooked into the oil and finally turpentine or petroleum distillates were added to reduce the viscosity for use.

Looking back in history we find that the early Egyptians used fossil resins in linseed oil. The protective coatings on their sarcophagi have been examined and point to such formulations. Both Pliny and Dioscorides described drying oils and resins dissolved in them. Galen in the second century A.D. mentions the use of lead and umber to speed the drying of oils. Theophilus Presbyter (10th–11th century A.D.) described making varnish much like the 19th century varnishes, but he used molten varnishes without liquid thinners. In 1520 rosin was mixed with sandarac gum and "run" in linseed oil. This was applied hot as a coating for cross-bows and armor.

VARNISHES OF THE PERIOD 1910–1920

Let us compare these early coatings with the varnishes of the years 1910–1920. In this later period the oils were largely linseed and some tung. These dried to a flexible film largely by oxidation. To give them luster and hardness a fossil resin was incorporated. There were dozens of such resins available, ranging in hardness and brilliance from Zanzibar copal or kauri, down through Manila, Congo, East India, Demerara, Pontianak, Sierra Leone, and damar. These resins had to be made compatible with oils by first "running," that is, by placing in the varnish kettle and destructively heating to about 690 F, driving off as volatile matter about 25 per cent by weight, in the course of which treatment the pale resin became very dark. The oil was then added to it and "driers," such as litharge, or the salts, resinates, or linoleates of lead, manganese, and cobalt, were cooked in. After the desired viscosity or "body" was obtained by cooking, the varnish was thinned to usable consistency with turpentine or mineral spirits. Rosin and rosin esterified with glycerine were also used as cheaper resins in place of fossil resins, and also because of better processing with tung oil.

Varnishes varied from elastic or "long" varnishes containing small amounts of resins to brittle, hard, or so-called "short" varnishes containing relatively large amounts of resins. The "longer" varnishes used as spar or exterior finishing varnishes were more durable, while the shorter varnishes were used as interior-trim or furniture varnishes and had relatively little exterior durability. The five main classes of varnishes made, together with their "length," that is, pounds of resin per gallon of oil, relative exterior durability, and drying time, are given in Table 1.

TABLE 1 MAIN CLASSES OF VARNISH, 1910–1920

Type of varnish	Length, lb resin per gal oil (approximate)	Relative durability, weeks[a]	Relative drying time, hr: Dry to touch	Relative drying time, hr: Hard to recoat
Finishing (for automobiles or railways)	1 1/2–2	50	10	48–72
Spars	2–3	32	4	30
Floor	4	8	4	24
Interior trim	5–7	4	4	36
Furniture	8–12	1	3	24–48

[a] This is a somewhat accelerated test made by exposing the varnish over steel panels on the roof at an angle of 45 deg to the sun facing south, in New York State.

DEMAND FOR RAPIDLY DRYING VARNISHES

Aside from the relatively poor durability of these coatings, their slow drying was a constant source of dissatisfaction. This criticism was particularly acute in the automobile industry where the finishing of the car was the narrow neck in the production bottle. As an example, let us cite the finishing schedules used by a prominent automobile manufacturer. Back in 1913 it took six weeks to apply the 22 distinct coats, 11 coats of primers, surfacers, roughstuff and glaze, 4 to 6 color coats, 2 coats of rubbing varnish, and 1 coat of finishing varnish. During the early 1920's this was speeded up to require 1 1/2 to 3 weeks on auto production. A typical finishing schedule of this period would be as follows:

1 coat primer	Air-dry	24 to 36 hr
1st coat surfacer	Air-dry	24 hr

Contributed by the Wood Industries Division and presented at a Meeting, Niagara Falls, N. Y., Sept. 17–19, 1936, of THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS.

2nd coat surfacer	Air-dry	24 hr
1 coat glazing putty	Air-dry	24 hr
Wet sand and dry		
1st color coat	Air-dry	24 hr
2nd color coat	Air-dry	24 hr
Wet sand and dry		
1st coat colored rubbing varnish	Dry	24 to 36 hr
2nd coat rubbing varnish	Dry	24 to 36 hr
Rub and stripe		
Final coat finishing varnish	Dry	48 hr

Due to the demand for speed in the finishing of automobiles, and because of discoveries made during the war, there appeared about 1923 the nitrocellulose lacquer coating. This type of coating was a chemical contribution made possible by the preparation of low-viscosity nitrocellulose and by the building up during the war of a new type of fermentation of corn which yielded the necessary solvent, butyl alcohol, and, by esterification, butyl acetate. A nitrocellulose lacquer does not dry by slow oxidation but by the evaporation of the volatile solvents. This evaporation leaves a hard film of nitrocellulose. This is, by itself, too brittle and must be plasticized by materials which will remain in the film, such as dibutyl phthalate and tricresyl phosphate, typical chemical products. Also, to give better adhesion, body, and luster, a resin must be added. At first these resins were mainly damar and esterified rosin. Such a lacquer when clear is no more durable than the old clear varnish, but when pigmented with zinc oxide and other pigments opaque to ultraviolet light the durability is much increased. Three coats of pigmented lacquer may be placed on an automobile allowing only 15 to 30 min between coats, and these were used to replace the color coats, rubbing, and finishing varnishes of the old system. Of course, the lacquers dried with a poor luster and had to be rubbed down to a smooth finish with wet sandpaper and polished with oil and rotten stone or other polishing agents to a satisfactory luster.

The saving in time was large enough, however, and the durability great enough to sweep varnishes practically entirely out of the automobile industry within four years. Other industrial uses of lacquers quickly developed, and finally it appeared in modified form as a brushing lacquer for use in the home.

DEVELOPMENT OF SYNTHETIC RESINS

This challenge to the varnish industry taxed its resources to the utmost and was met by two distinct phases of work. The varnish manufacturer turned to his chemist and became a lacquer manufacturer. He plunged into new types of raw materials, new types of equipment, and utilized his knowledge of basic finishing methods and schedules. At the same time, however, the chemists went to work to make varnishes quicker drying and more durable. New resins were discovered which achieved drying of oil coatings largely by polymerization instead of oxidation, and the modern "quick-drying" varnish and enamel resulted.

These first synthetic resins were phenol-formaldehyde combinations dispersed in rosin or esterified rosin. Their principal contribution was speeding drying to about four hours with a slight increase in durability. Then followed later the straight phenol-formaldehyde resin of today which, without modification by rosin or other agents, is oil-soluble and which revolutionized conceptions of oil length and durability. These offered the varnish manufacturer entirely new standards of durability and chemical resistance. They quickly displaced natural resins and slow-drying schedules in many uses and opened up entirely new fields for the products of the paint and varnish industry. At the same time other types of synthetic resins were appearing, based on combinations of phthalic anhydride and glycerine. These likewise increased the durability of nitrocellulose lacquers by displacing all or part of the natural resins and found their way into various types of baking and more recently air-drying finishes.

Today, through the use of low-temperature baking synthetic resins, the automobile manufacturer is achieving still faster schedules which require no sanding and polishing to produce durable gloss finishes.

The first of the synthetic resins to be used in quick-drying finishes were the albertols developed by Kurt Albert in Germany. These consisted of a relatively small proportion of phenol-formaldehyde dispersed in rosin or ester gum. The straight or 100 per cent phenol-formaldehyde resin, as invented by Leo H. Baekeland in 1908, was widely known in molded, transparent cast, or laminated materials. These 100 per cent phenol-formaldehyde resins are familiar in telephones, distributor heads, electrical attachment plugs, caps, knobs, handles, and countless cases and parts requiring resistance to moisture, hardness, high dielectric strength, inertness, infusibility, and mechanical strength. Other forms are familiar as laminated table and bar tops, dentures, brake lining, the bond of grinding wheels, and modern waterproof veneer adhesives. The resin in all these forms, however, is insoluble in the drying oils used in varnish manufacture unless first modified with rosin or other agents. For years research work continued on the problem of making these resins oil-soluble, and eventually the first 100 per cent phenol-formaldehyde resin for this purpose was announced. This new basic raw material for the varnish industry immediately leaped into prominence because, in addition to quick drying, it offered a new order of durability, and resistance to moisture, alkalies, and acids, in comparison with the former natural resin or reduced phenolic coatings.

Another type of synthetic resin which has been developed for coatings during the past few years is based on the reaction between phthalic anhydride and glycerine modified with oil acids or resins. These are the so-called alkyds developed by Arsem, Kienle, Ellis, Hopkins and McDermott, and others. The alkyd resins have also changed substantially the procedures in paint and varnish. Today the alkyds and the phenol-formaldehyde resins constitute the basis of the modern finishes. In addition there are several other new types of resins which may grow in importance but which today are used only in minor quantities. Among these are the vinyls, the petroleum-base hydrocarbon resins, and the rubber derivatives.

While the introduction of the new types of finishes was largely in response to the automobile industry's demand for increased speed and durability, the synthetic-resin finishes have made notable contributions to all protective coatings. Especially have they proved valuable in protective finishes for wood due to their high moisture resistance.

MOISTURE RESISTANCE AND WOOD PROTECTION

The importance of a moisture-resistant finish in the protection of wood has been emphasized by the results of many workers. Much of this work has been done at the U. S. Forest Products Laboratory at Madison, Wis. Dr. F. L. Browne of that laboratory states (1):[1] "Weathering of wood is attributed principally to the disintegrating effect of internal stresses set up in the wood as the result of fluctuating moisture content of those portions exposed directly to the weather. The hygroscopic, swelling character of wood and the slow transfusion of moisture through it give rise to a 'working' of the wood near the exposed surface against the more sluggishly changing

[1] Numbers in parentheses refer to Bibliography at end of paper.

TABLE 2 EFFECT OF REPEATED WEATHER EXPOSURE ON MOISTURE-EXCLUDING EFFECTIVENESS OF VARIOUS VARNISHES (HUNT)

Varnish	Amount of moisture absorbed after weather exposures of various times in weeks, g per sq ft: 0	6	12	18	24	30	48	54	66	78
Phenolic resin spar	1.43	1.81	1.05	1.33	2.28	2.48	4.10	4.0	5.03	11.71[a]
Spar 1	27.30	26.48	22.65	21.70	...	27.80	[b]	...	...	...
Spar 2	25.51	...	42.00	38.75	27.70	[b]	...	...	...	...
Spar 3	44.48	44.48	47.60	16.86	[b]	...	...	...	...	...
Spar 4	32.84	39.32	43.90	14.00	43.05	[b]	...	...	...	...
Spar 5	43.10	37.42	44.25	13.81	50.10	[b]	...	...	...	...
Spar 6	20.10	21.60	37.90	17.43	18.00	21.60	31.60	[b]	...	...
Spar 7	25.70	24.95	29.80	31.80	23.31	30.65	[b]	...	...	...
Spar 8	19.90	24.38	31.70	23.70	36.00	37.70	...	...	...	...

[a] Still in test after 78 weeks.
[b] Discontinued due to failure.

TABLE 3 GROUP C—THREE COATS OF PAINT—AVERAGE EFFECTIVENESS ON FOUR WOODS (BROWNE)

Series 700	Exposure, no. of months: (Orig.) 0	6	12	18	24	30	36	End	Integrity (durability in months or rating after 36 months): S. pine	D. fir	Wh. pine	Redwood
702 White lead in linseed oil	72	73	69	63	53	35	37	2	27	30	F—	F
703 White lead in phenolic-resin-treated oil	88	90	89	80	91	85	88	88	34	F	G	G

TABLE 4 AVERAGE EFFECTIVENESS RATING (BROWNE)

Series 500 (without pigment)	Orig.	Time, months: 6	12	18	E. F. end, avg
516 Linseed oil	21	21	10	..	—1
514 75 gal ester-gum varnish	35	32	17	..	—1
515 33 gal ester-gum varnish	65	55	31	..	—3
512 Phenolic-resin-treated oil	66	63	50	46	26
513 Phenolic varnish	73	69	59	57	41

interior. Other factors, such as mechanical abrasion and photochemical oxidation, play some part, but swelling and shrinking in response to changing atmospheric conditions are thought to be the leading part." He then goes on to describe the method for determining water resistance as outlined by Dunlap (2). In this, wood specimens $^5/_8 \times 4 \times 8$ in. with corners rounded are seasoned at 60 per cent relative humidity and 80 F and are coated similarly on all surfaces. They are then subjected repeatedly to the following cycle of conditions, being weighed before and after each exposure:

(1) 60 per cent relative humidity, 80 F, for two weeks
(2) 95–100 per cent relative humidity, 80 F, for two weeks
(3) 60 per cent relative humidity, 80 F, for two weeks
(4) Outdoor exposure, 60–80 F, for six weeks

The gain in weight during step 2 is the amount of moisture absorbed through the coating.

George M. Hunt (3), in describing similar moisture-resistance tests on wood, brings out the great improvement of the 100 per cent phenolic spar varnish in contrast with eight representative spar varnishes of the previous type, as shown in Table 2. It will be noted that the eight older varnishes have an initial moisture-proofing efficiency of about 60 per cent, which falls off to zero after 36 to 48 weeks' exposure. The phenolic varnish, on the other hand, has an initial efficiency of 92 per cent, and after 78 weeks of exposure still has an 86 per cent rating and is still in the test. A covering of three coats of linseed oil followed by two coats of wax has an initial efficiency of only 31 per cent. Effectiveness rating, or efficiency of the various coatings is calculated by comparison with the weight of moisture absorbed by the base panels, as follows:

$$\frac{A - B}{A} \times 100 = \text{percentage efficiency}$$

where A = the weight of moisture absorbed by base panel and B = the weight absorbed by painted panel.

In 1933 F. L. Browne (4) published a further study of house paints on wood, measuring their moisture-retarding efficiencies. He points out that since coatings of paints and varnish retard the exchange of moisture between wood and its environment, their effectiveness depends largely on the nature of the coating material. Their effectiveness against moisture exchange determines the degree of protection that they afford wood. The method of testing on four species of wood is outlined in detail. This work was followed up in another of Dr. Browne's papers (5) in which he concludes that "protection can be measured by quantitative methods since it depends upon the effectiveness of the coating in retarding the exchange of moisture between wood and its environment." The effectiveness of the coating against moisture was measured quantitatively before exposure and at six-month intervals thereafter on Southern pine, Douglas fir, white pine, and redwood. An excerpt from this paper, Table 3, illustrates the fortifying effect of the phenolic resin with regard to moisture resistance and integrity.

Another series (500) gave the average effectiveness of five clear vehicles over the four woods—Southern pine, Douglas fir, white pine, and redwood, Table 4.

Edwards and Wray have also published data on moisture penetration and methods of measurement. In 1927 (6) they presented data in confirmation of the conclusions of Dunlap and Browne that paint and varnish coatings continue to protect wood adequately against weathering only so long as they maintain a reasonable degree of moisture-excluding efficiency.

The methods used by the Aluminum Company Laboratories for measuring permeability to moisture are described by Wray and Van Vorst (7). One of these methods is for films alone, which were prepared by spinning on amalgamated tin panels. After drying, disks 10.5 cm in diameter were stripped and sealed with wax over shallow Petrie dishes partially filled with an active moisture absorbent (activated alumina). The dishes were weighed and then held 48 hours at 95 per cent humidity at 27 C. They were reweighed at intervals to determine the amount of moisture passing through the film. The permeability is expressed in milligrams of moisture passing through one square centimeter of film per hour.

In comparing data, however, it is simpler to use the reciprocal of this value, called the moisture impedance of the film. This method offers the obvious advantage of yielding a value for each film not influenced by any base material.

Wray and Van Vorst's second method is to coat the finish on both sides of thin panels of Western yellow pine. After

ABLE 5 MOISTURE IMPEDANCE AND EFFICIENCY OF VARIOUS COATINGS IN EXCLUDING MOISTURE AS DETERMINED BY THREE DIFFERENT METHODS

(Excerpt from Wray and Van Vorst, Table II)

Coating	No. of coats	Films alone, moisture impedance[a]	Films on 0.635-cm pine Efficiency, per cent	Films on 0.635-cm pine Moisture impedance[a]	Efficiency by Forest Products methods, per cent
Ester-gum varnish	1	2.4	28	6.3	...
	2	3.1	62	12	...
	3	4.6	76	20	26
Glycerol-phthalate varnish	1	4.1	58	11	7
	2	5.9	80	24	19
	3	8.6	81	26	29
50-gal phenolic-resin varnish	1	6.5	75	19	12
	2	12.0	86	34	36
	3	13.0	91	50	43

[a] Reciprocal of mg of moisture per sq cm per hr.

thorough drying, small disks about 5.3 cm in diameter are cut, the edges sealed with aluminum foil in a wax composition, and sealed into wide-mouth bottles of activated alumina. After weighing, these bottles are held at 95 per cent humidity and 27 C for weekly periods and reweighed. An excerpt, Table 5, from Table II of their paper shows a comparison of three types of vehicles.

Although the 50-gallon phenolic varnish in Table 5 shows high values for moisture resistance, it should be noted that with increased proportion of the resin content its resistance properties as well as its toughness would increase.

The usual laboratory method for determining water resistance is run qualitatively by coating a tin or steel panel and immersing either at room temperature or in boiling water for a specified period. For example, the A.S.T.M. water test (D-154-28)-19 is as follows: Varnish is poured on tin panels and dried 48 hr. That part uppermost during drying is then placed in about 7 cm of distilled water for 18 hr. The panel is then removed, dried, and time for whitening to disappear is noted.

During the past few years, due largely to the improvements that have been made possible by development of the 100 per cent phenolic resins and alkyd resins, many of the older specifications and tests have become obsolete and do not assure the procurement of today's highest quality finishes. Details of modern specifications are given in a recent paper by Moore and Turkington (8). As an example of the change in severity let us compare tests for spar varnishes as shown by federal and Navy specifications, Table 6.

It will be noted from Table 6 that the varnish industry has been able to meet much more rigid specifications during the past few years. The fourth column (V-10c specification) is met by a varnish containing 28 per cent straight phenolic resin to 72 per cent drying oil. This is called a 33-gallon varnish. By increasing the proportion of the synthetic resin, the resistance and durability properties and speed of drying are also increased. Thus the sixth-column specification for a chemically resistant coating is met by a varnish, the nonvolatile content of which contains approximately 50 per cent of the phenolic resin to 50 per cent drying oil. Where maximum protection for wood products is desired, this type of varnish will air-dry to give extremely high resistance to moisture and chemicals. For example, it is used to protect wood construction in the following forms:

Chemical-laboratory table tops and hoods.
Tanks for water and dilute solutions.
Plant equipment such as filter presses and frames.
Stirring paddles, dye sticks, and vats in the dye and rayon industries.
Pasteurizing equipment, trays.
Patterns, mechanical forms, bobbins, handles, leather-tanning bars.
Sealer for laminated or veneered doors, to prevent delamination and buckling by keeping moisture out of trimmed edges.
Alcohol-resistant bar and table coatings.

Another problem that has long vexed the automobile-body builder and others using wood construction is the fungus growth and decay in warm, humid climates. This is especially prevalent in the high-humidity section of the South, the Canal Zone, and the Philippines. The durability and extreme resistance to moisture and attack by vegetable or animal organisms of a coating of the foregoing type offers confidence in the solving of this problem.

TABLE 6 SPECIFICATIONS FOR SPAR VARNISH

Specification no.	Old-type Federal TT-V-121, up to 1935	New-type Federal TT-V-121a, revised, 1935	Old-type Navy Dept. 52-V-12B, 5/1/25	New-type Naval Aircraft, V-10c, revised, 1934	New-type A.C., spec. no. 13 for maximum durability as an aluminum vehicle	Special 100 per cent phenolic chemical resistant type
Cold water	18 hr[a]	72 hr[a]	18 hr	.....	96 hr	7 days
Boiling water	15 min	60 min	15 min	7 hr[b]	6 hr at 167 F	24 hr
Kauri reduction, test for flexibility, per cent	50	100	50	140	140	.....
Drying time						
Set to touch, hr	5	0.5–2	5	2.5	1–3	1
Hard, hr	24	8	24	6	18	3
Resistance to 5 per cent caustic soda, hr	Not required	Not required	Not required	24	6	96
Resistance to 5 per cent acetic acid, hr	Not required	Not required	Not required	24	24 (4%)	96 (15% sulphuric acid)
Gasoline resistance, hr	Not required	Not required	Not required	.....	48	6
Resistance to 50 per cent alcohol, hr	.....	.....	.....	.....	.....	6

[a] Panels to be examined 2 hr after removal from water. [b] Panels to be examined 5 min after removal from water. A.C. = Aluminum Co. of America.

(Continued on page 634)

THE REYNOLDS NUMBER

A Simplified Explanation of the Significance of This Important Quantity and Examples of Its Use in Aerodynamics and Hydraulics

By BORIS A. BAKHMETEFF

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[With a view to making the significance of the Reynolds number clear to a wide audience, Professor Bakhmeteff was asked by the Applied Mechanics Division and the Metropolitan Section of The American Society of Mechanical Engineers to deliver a lecture on the subject at a meeting held in New York, N. Y., on April 8, 1936. Professor Bakhmeteff succeeded so well in this assignment that numerous requests for a printed copy of the lecture were received. Because of this, and in order that a wider circle of engineers might profit, Professor Bakhmeteff was asked to prepare the following summary of the lecture for publication.—EDITOR.]

TO GRASP the significance of a term, it is useful at times to resort to historical retrospection. With respect to our present study of the Reynolds number the stage is set 25 to 30 years ago. Aeronautics is just coming to the fore. Scientists are eagerly striving to obtain basic facts in what is to become mechanics of fluids. An important problem is that of "parasitic drag," meaning the resistance encountered by solid bodies when moving in fluid media. The simplest case is that of a sphere. Eifel in Paris and Prandtl in Germany are experimenting in newly built wind tunnels, reducing observations to the terms of the well-known Newton formula

$$\text{Resistance force} = \psi A \rho U^2/2 \quad \ldots\ldots\ldots\ldots [1]$$

where A is the projected cross-sectional area, ρ the mass density, and U the velocity of flow.

It is easy to imagine the bewilderment and confusion when, instead of obtaining more or less identical coefficients, Prandtl found ψ to be near 0.4, while Eifel, working with larger spheres and at higher velocities, obtained values on the order of 0.17. This confusion, enhanced by other inconsistent data coming from further sources, is well reflected by Prandtl's reminiscent remark "that the very thought of model tests which are based on the Newton law seemed to totter."

The present-day conception is illustrated by Fig. 1, taken from a cornerstone Göttingen summary.[1] It embodies observations made under widely varying conditions. Some of the points represent wind-tunnel data; others are experiments on rising air bubbles, or on small heavy spheres, dropping in viscous media. Again, the fluids are different. In some cases the fluid is air, in others water or oil. We know now that the kind of fluid is immaterial. In fact, all fluids exhibit analogous characteristics and will result in identical coefficients when made to work under *similar* conditions.

The outstanding feature exhibited by Fig. 1 is that the different points when plotted gather into a single unified curve. The individual coefficients vary greatly, although each occupies its proper place, and they feature in their entirety regular and continuously changing conditions. The Prandtl and Eifel experiments simply fall into two different zones, I and II in Fig. 1, a fact which obviously indicates the existence of two radically different types of motion.

What has made this orderly representation possible? What has brought harmony into the mass of contradictory and apparently inconsistent results? The answer lies in having used the proper term of reference, in having plotted the experimental values versus the Reynolds number; a suitable flow characteristic of the form

$$R = \frac{UD}{\nu} = \frac{UD}{\mu/\rho} \quad \ldots\ldots\ldots\ldots [2]$$

In Equation [2] D is the diameter of the sphere, while U is

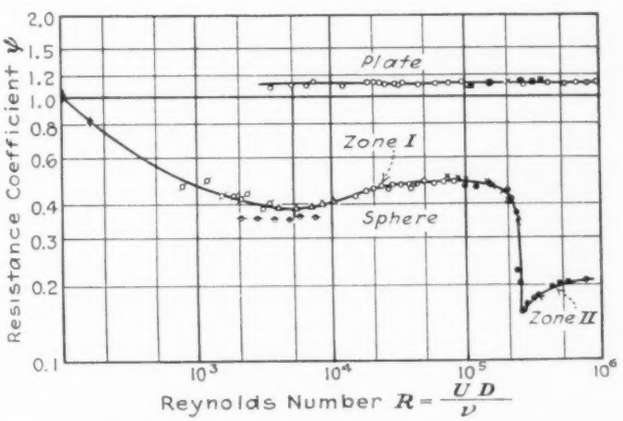

FIG. 1 RESISTANCE OF A SPHERE IN TERMS OF THE REYNOLDS NUMBER

the velocity of flow. The denominator ν is the so-called kinematic viscosity, i.e., the ratio of the absolute viscosity μ to the mass density ρ.[2]

An other example of this remarkable capacity of the Reyn-

[1] "Versuche über den Luftwiderstand gerundeter und kantiger Körper," Ergebnisse der Aerodynamischen Versuchsanstalt zu Göttingen, part 2, 1923, p. 29.

[2] In evaluating the kinematic viscosity it is imperative to use consistent units. Taking the pound as the unit of weight, as it is customary in engineering practice, the mass density

$$\rho = \frac{\text{weight per unit volume}}{\text{acceleration of gravity}} = \gamma/g$$

Thus the average density of water is 62.4/32.2 = 1.94 lb sec²/ft⁴. Values of viscosity coefficients, expressed in fps units, for a temperature of 60 F and atmospheric pressure, are

	μ lb × sec/ft²	ρ	ν ft²/sec
Water.....	23×10^{-6}	1.936	11.19×10^{-6}
Air.....	37.2×10^{-3}	23.8×10^{-4}	15.6×10^{-6}

Figures for other temperatures and pressures are easily obtained by using the relative value of the respective viscosities and densities.

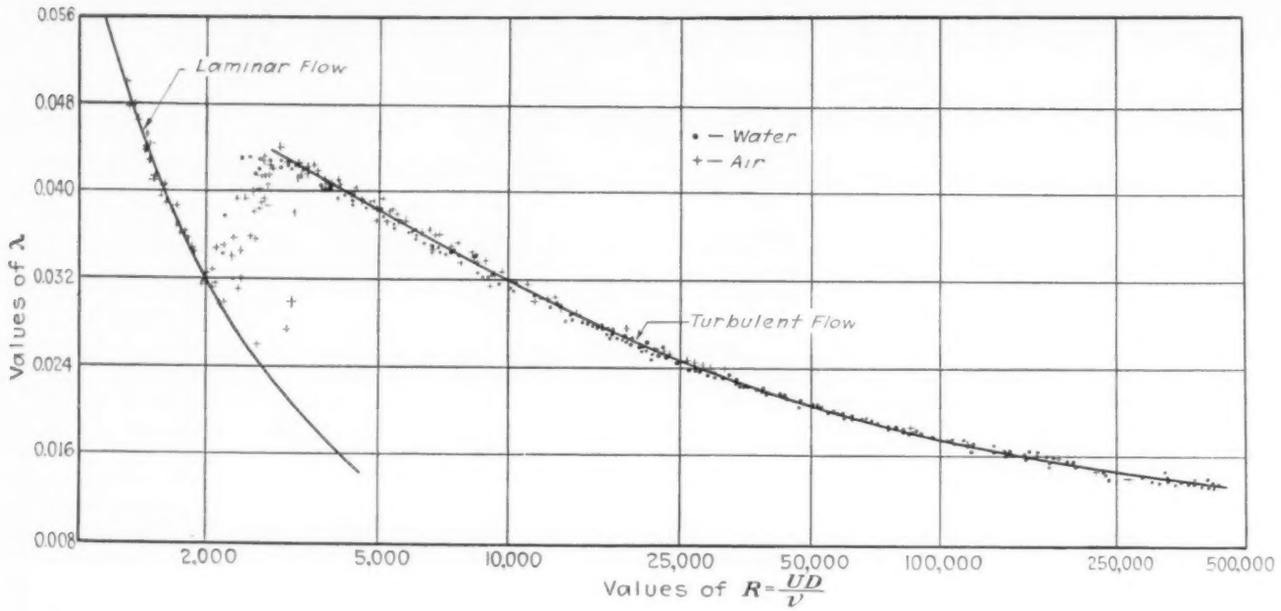

FIG. 2 RESISTANCE COEFFICIENTS λ FOR SMOOTH PIPES IN TERMS OF THE REYNOLDS NUMBER

olds number to "organize" experimental results is given in Fig. 2, featuring pipe-friction coefficients in the customary formula

$$\text{Pressure-loss gradient} = \frac{p_1 - p_2}{l} = \lambda \frac{1}{D} \rho \frac{U^2}{2} = \frac{\lambda}{D} \gamma \frac{U^2}{2g} \quad \ldots\ldots\ldots [3]$$

The curve is derived from a crucial test by Stanton and Pannell,[8] water and air having been successively forced through the same pipes.

THE FLOW PATTERN—DYNAMIC SIMILARITY

What then is the Reynolds number? What are its physical meaning and essential features? In answering this question we first introduce the notion of a "flow pattern." In distinction to a solid, and particularly machinery, where the moving parts are definitely linked by intermediate mechanism, a fluid medium is a continuum filled with myriads of individual particles, practically free to move in every direction. Except as it is restrained by the solid boundaries, the internal flow of the fluid may assume a variety of forms, each characterized by a certain picture of streamlines, with a corresponding distribution of velocities and pressures. Each possible form of motion may be qualified by the term "flow pattern." Thus each individual condition is said to have its particular flow pattern, different and distinct from others. It may be surmised that motions resulting in identical coefficients follow analogous patterns. Similar patterns are a part of a broader notion—"dynamic similarity."

To be more concrete, imagine the motion of a prototype and of a model, Fig. 3, having geometrically similar forms and differing only in length scale l_{pr}/l_m. Assume further that the two bodies are moving in different media, such as air and water. In order to qualify the two fluid patterns as being similar, one motion must reproduce the other to scale. The respective streamlines must be analogous in shape. The velocity distributions must also copy each other, the copies, however, having their own scale, usually different from the length scale. So in addition to l_{pr}/l_m we shall have a u_{pr}/u_m velocity scale, this being the ratio of the respective velocities at any analogous point of the model and of the prototype. A velocity scale on the other hand is equivalent to a time scale, the latter being $t_{pr}/t_m = (l/u)_{pr}/(l/u)_m$.

A useful illustration is a planetarium. The firmament is reproduced to a certain length scale, while the motions of the planets with their respective velocities copy the apparent movements of the celestial bodies to a prearranged time or velocity scale.

Returning to the curves Figs. 1 and 2, as might be surmised, identical coefficients of resistance obtained for bodies of different size with different velocities and in different fluid media point to the fact that in all such cases the flow patterns must have

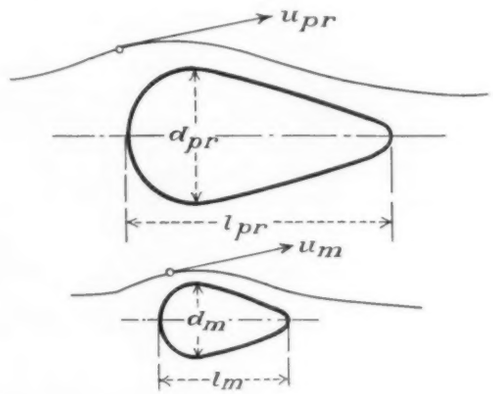

FIG. 3 SIMILAR MOTIONS OF A PROTOTYPE AND A MODEL

been analogous. The Reynolds number thus appears as a mark of similarity of fluid pattern, a symbol of dynamic similarity.

An elementary mathematical reasoning will further elucidate the case. No matter how complex the motion is in its entirety,

[8] "Similarity of Motion in Relation to the Surface Friction of Fluids," by T. E. Stanton and J. R. Pannell, Philosophical Transactions of the Royal Society of London, series A, vol. 214, part 1, 1914, p. 199.

the movement of each individual particle is governed by the simple Newton law

$$\text{Mass} \times \text{acceleration} = \text{resultant force}$$

$$M\,du/dt = \Sigma F \quad \ldots\ldots [4]$$

In Equation [4] ΣF means the sum total of all forces, internal and external, acting on the particle in question. The left-hand portion of the expression taken with the negative sign is the "inertial force." Designating $-M(du/dt) = I$, and applying Equation [4] to analogous parts of the prototype and of the model we may write symbolically

$$\left.\begin{aligned} I_{pr} + \Sigma F_{pr} &= 0 \\ I_m + \Sigma F_m &= 0 \end{aligned}\right\} \quad \ldots\ldots [5]$$

As to forces acting in a fluid, they may be gravity G, pressures P, capillary forces C, and finally friction Fr. So instead of Equation [5] we have, in the most general case

$$\left.\begin{aligned} I_{pr} + (G + P + C + Fr)_{pr} &= 0 \\ I_m + (G + P + C + Fr)_m &= 0 \end{aligned}\right\} \quad \ldots\ldots [6]$$

To make the motions of the prototype and of the model similar, all members of Equation [6] should be in the same ratio. In other words

$$\frac{I_{pr}}{I_m} = \frac{G_{pr}}{G_m} = \frac{P_{pr}}{P_m} = \frac{C_{pr}}{C_m} = \frac{Fr_{pr}}{Fr_m} \quad \ldots\ldots [7]$$

One must now judicially restrict the number of agencies to be considered. Capillary action is generally of no account in engineering problems. Internal pressures, on the other hand, are not independent agencies. They are either caused by gravity (hydrostatic pressures) or represent the dynamic effect of accumulated accelerations, as exemplified in the velocity heads in the Bernoulli equation. Thus the only independent agencies left are gravity, and friction forces originating in viscosity.

Gravity is the principal agency acting in open flow with a free surface, as in hydraulic structures or in the case of ship resistance caused by surface waves. These cases constitute a special group subjected, so far as dynamic similarity is concerned, to the "Froude number."

In closed flow (pipes, hydraulic machinery) or when solids are fully immersed in a fluid (submarine, aircraft, vehicle) so that no free surface enters into consideration and gravity is balanced by buoyancy, the only active agents are friction forces arising from viscosity. Therefore in these cases, which are of particular interest to the mechanical engineer, the condition of dynamic similarity is reduced to

$$\frac{I_{pr}}{I_m} = \frac{Fr_{pr}}{Fr_{mo}} \quad \ldots\ldots [8]$$

or by reversing

$$\left(\frac{I}{Fr}\right)_{pr} = \left(\frac{I}{Fr}\right)_m \quad \ldots\ldots [9]$$

Dynamic similarity will thus prevail when, at any analogous points of the two motions, the ratios, inertial force/viscous force, will be identical.[4]

[4] It should be stated at this point that it is impossible to satisfy simultaneously the requirements of dynamic similarity with regard to both gravity and friction forces. Where, as in ship resistance, or in certain hydraulic phenomena, both agencies come into action, the engineer will have to make the choice and decide which of the two he will have to consider as the principal factor and to which he will have to cater in making model tests.

A simple dimensional reasoning shows that this ratio is exemplified by the Reynolds number. To prove, one should express the ratio I/Fr through the length and velocity parameters l and u constituting the aforementioned scales. The dynamic characteristics of the fluid medium itself will be the respective densities and viscosities.

With regard to I, remembering that mass $\times$ acceleration = volume $\times$ density $\times$ velocity $\div$ time, we have the dimensional expression

$$I \cong l^3\,\rho\,u/t = l^3\,\rho\,u/(l/u) = l^2\,\rho\,u^2 \quad \ldots\ldots [10]$$

The viscous force acting between two plates, Fig. 4, sepa-

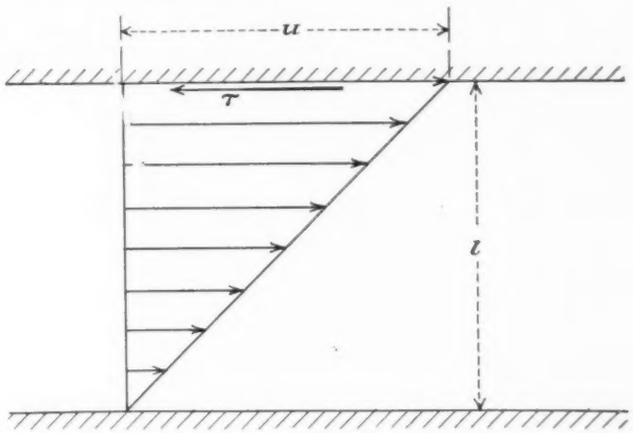

FIG. 4 DETERMINING THE VISCOSITY STRESS τ

rated by the distance l, and moving relatively at the rate of u is

$$\text{Area} \times \mu \times u/l$$

The dimensional expression for viscous action at any point of the system is thus proportional to

$$Fr \cong l^2\,\mu\,u/l = l\,\mu\,u \quad \ldots\ldots [11]$$

Accordingly, the sought-for ratio is

$$\frac{I}{Fr} = \frac{l^2\rho u^2}{l\,\mu u} = \frac{l\,u\,\rho}{\mu} = \frac{lu}{\nu} = R \quad \ldots\ldots [12]$$

The physical essence of the Reynolds number is thus revealed. Identical Reynolds numbers mean analogous ratios of the inertial to the viscous forces, analogous ratios leading to similar patterns of flow.

We shall now briefly review the principal cases where the Reynolds number is most usefully applied.

TESTING MODELS

Broadly speaking, we seek to produce motion in the model similar to the actual flow in the prototype. The model scale l_{pr}/l_m and the prototype speed u_{pr} being given, the problem is to determine the proper test velocity u_m. Similar flow patterns require identical Reynolds numbers. Accordingly, in the light of Equations [9] and [12] the test velocity is

$$u_m = u_{pr}\left(\frac{l_{pr}}{l_m}\right)\left(\frac{\nu_m}{\nu_{pr}}\right) \quad \ldots\ldots [13]$$

For the same fluid media ($\nu_{pr} = \nu_m$), the velocities are in inverse proportion to the length scales, which usually makes u_m unpractically high. To reduce, we can make use of the

ratio $\frac{\nu_m}{\nu_{pr}} = \frac{\mu_m}{\mu_{pr}} \times \frac{\rho_{pr}}{\rho_m}$ in Equation [13] by appropiatrely reducing the kinematic viscosity of the test fluid. Thus by substituting water for air and by towing the model in a tank, we may reduce the test velocity about thirteen times.[2] Another way is to increase the density ρ_m, as is done in the so-called "variable-density" air tunnel at Langley Field, where aircraft are tested in compressed air.

Testing a model of an aircraft or of a vehicle is a case where Equation [13] applies directly. Occasionally, the expression

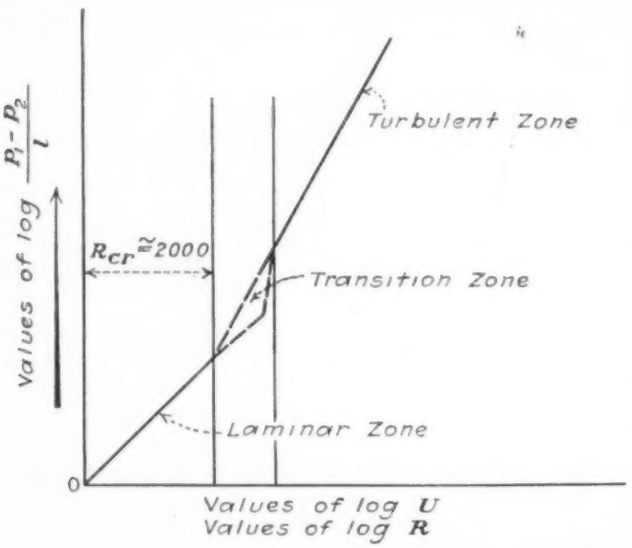

FIG. 5 THE REYNOLDS DIAGRAM ILLUSTRATING LAMINAR AND TURBULENT MOTION IN A PIPE

for the test velocity is composite, but the reasoning is mostly very simple. Thus, suppose the case were disk friction, and one in which we were measuring the friction torque on a model with a diameter ratio of d_m/d_{pr}. In determining the revolutions n_m which would insure dynamic similarity, it must be remembered that the lineal velocities, which enter into the Reynolds number, in case of rotation will be proportional to diameter $\times$ revolutions. Therefore identical Reynolds numbers will require $\frac{d_m(d_m \times n_m)}{\nu_m} = \frac{d_{pr}(d_{pr} \times n_{pr})}{\nu_{pr}}$ and hence the test revolutions will be

$$n_m = n_{pr}\left(\frac{d^2_{pr}}{d^2_m}\right)\left(\frac{\nu_m}{\nu_{pr}}\right)$$

STATE OF MOTION

With regard to Fig. 1 the existence of two different types of motion has been mentioned. The classical example, however, is the well-known distinction between "laminar" and "turbulent" flow in pipes, first established by Osborne Reynolds[5] and elucidated in Fig. 5. The broken line indicates the change of the law of resistance. The latter is at first proportional to the first power of velocity, this being in the zone of laminar flow where the filaments actually constitute congruent streamlines conserving their identity. Then in the zone of turbulent flow, reached at higher velocities, the resistance varies almost as the square of the velocity, and the highly increased losses are principally caused by a process of turbulent mixing, a conventional term used to describe the altogether irregular transversal and eddy movements of the individual particles.

Between lies a transition zone with a demarcating "critical" velocity. The Reynolds number is a criterion demarcating the two states of flow. $R_{cr} \cong 2000$, indicated in the drawing, is the customary value of a delimitating "lower critical" velocity below which the flow pattern is always laminar, so that even an initially turbulent movement settles down into a stabilized streamline motion.

Fluid motion in the laminar state, with a permanent streamline pattern, was qualified by Reynolds as "stable," this "stability" feature being lost in transition to the turbulent state, which is essentially "unstable."

To invoke a comparison, imagine a procession of people or the marching of a military detachment; when the pace is slow and the "depth" of the columns is not excessive, order and alignment are easily preserved. Increase the speed or the depth of the ranks and stability of form becomes imperiled. A step further and utter confusion may be on hand. The stampede of a panicky crowd or of a herd of frightened animals may serve as an example. The heavier the individual units (cavalry vs. infantry; elephants, etc.) the greater the danger. Obviously the size of the group, its speed, and its ponderosity

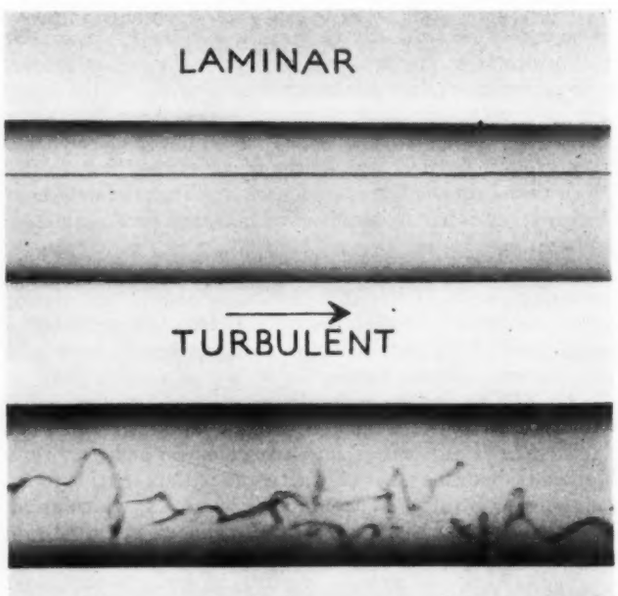

FIG. 6 TURBULENCE ORIGINATING IN A REYNOLDS APPARATUS (The dark line represents a colored filament.)

are factors promoting instability. On the contrary, if by some internal tie the relative internal mobility between the units were to be reduced, stability would be enhanced. By analogy, in pipe flow the diameter, the velocity, and the density will be unstabilizing agencies, while viscosity, which reduces internal mobility, will work for stability. The ratio of these factors $DU\rho/\mu$ finds symbolical expression in the Reynolds number, the numerical value of which thus becomes a relative index of instability.

In a pipe the critical value of the Reynolds number directly differentiates the two possible types of motion, which in their

[5] "An Experimental Investigation of the Circumstances which Determine whether the Motion of Water shall be Direct or Sinuous, and of the Law of Resistance in Parallel Channels," by Osborne Reynolds, Philosophical Transactions of the Royal Society of London, series A, vol. 174, part 3, 1883, pp. 935–982.

initial stages are illustrated by Fig. 6. In the case of a sphere, the two zones of Fig. 1 are conditioned by the form of the "wake" back of the body. The latter is caused by the flow separating from the solid. Low resistance (zone II) corresponds to a smaller wake, with separation deferred. Fig. 7 illustrates a celebrated test in the Prandtl laboratories where reduced wake is made directly visible. Prandtl made clear, moreover, that deferred separation, resulting in lower resistance, is conditioned by changing the flow in the film adjacent to the body from laminar to turbulent.[6] This film is Prandtl's famous "boundary layer." Paradoxical as it seems, a turbulent boundary layer, while augmenting skin friction, enhances the resistance of the flow to separation and thus tends to reduce the "form" resistance caused by the underpressure in the wake.

SKIN FRICTION

The case of skin friction is typical in that the Reynolds number is used for studying in more detail phenomena taking place directly in the boundary layer. Consider the simplest case of a thin plate placed in line with the flow, Fig. 8. There arises a purely tangential friction force, "skin friction," studied in the past by Froude. At present the problem is approached in the terms of Prandtl's boundary layer, analyzing how the retarding effect of friction, initiated at the contact point c, gradually penetrates into the undisturbed fluid. In fact the line c-b demarcates a zone of increasing thickness δ, within which flow has been materially affected by the friction originating on the plate surface, while outside of the layer the mass of the fluid is practically undisturbed and still moving at the original velocity U. The local friction intensity τ at a point x is expressed by the customary formula

$$\tau = \rho\, c_f\, U^2/2 \qquad [14]$$

where c_f is a coefficient varying with the distance x, depending on the velocity distribution in the layer and primarily on the boundary-layer thickness δ. One may estimate theoretically the variation of the local coefficient from point to point. However, in engineering practice one usually operates with a mean coefficient $\bar{c}_f$, which represents the aggregate average effect over the length x. Obviously, the $\bar{c}_f$ value must change with the distance x. Accordingly, the Reynolds-number characteristic is introduced in a varying form

$$R_x = Ux/\nu \qquad [15]$$

The theory indicates that both the relative layer thickness and the friction factor vary as $1/R_x^{0.5}$.

Within the scope of this article, the usefulness of the concept is demonstrated by Fig. 9, in which experimental values of $\bar{c}_f$ are assembled together with the two lines featuring the theoretical values derived by von Kármán.[7] The curves correspond respectively to the boundary layer in laminar and in turbulent state.

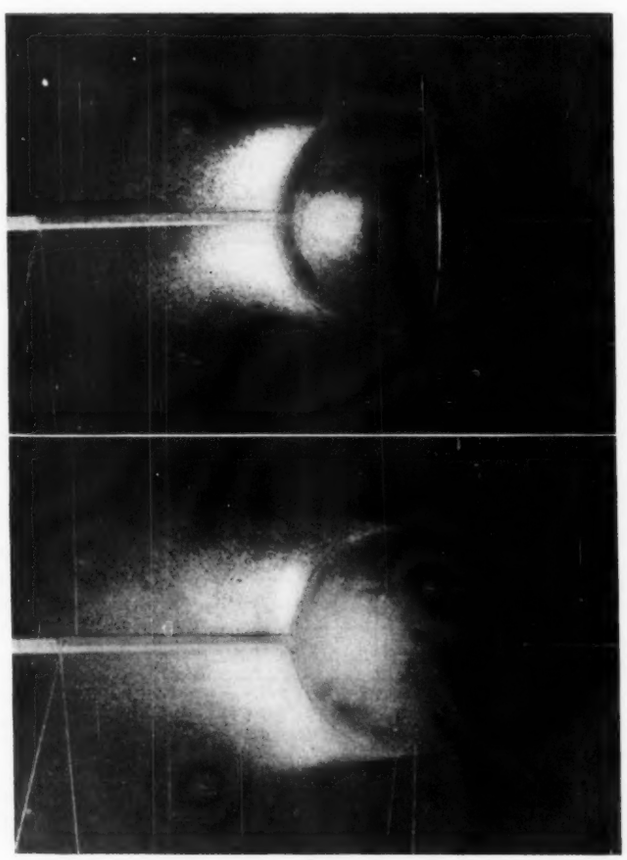

FIG. 7 THE WAKE BEHIND A SPHERE (PRANDTL)
(The upper illustration corresponds to laminar and the lower to turbulent motion in the "boundary layer," zones I and II in Fig. 1.)

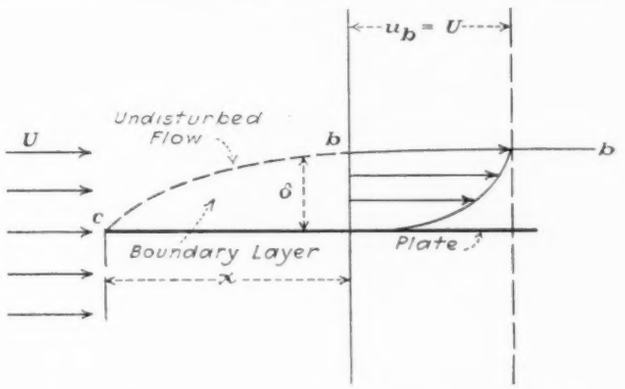

FIG. 8 THE "BOUNDARY LAYER" IN THE CASE OF A THIN PLATE

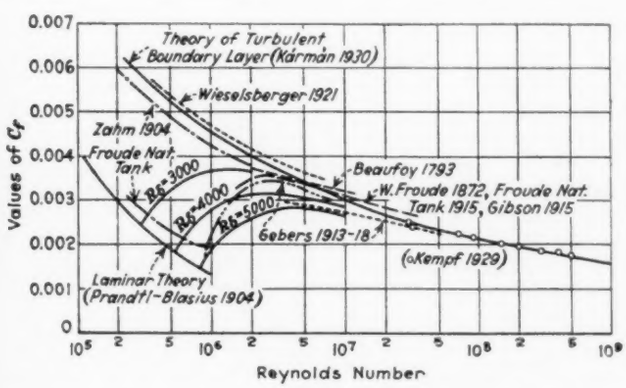

FIG. 9 SKIN-FRICTION COEFFICIENTS FOR SMOOTH PLATES (VON KÁRMÁN)

[6] "Über den Widerstand von Kugeln," by L. Prandtl. Göttingen Nachrichten Mathematische-physikalische Klasse, 1914, p. 777.

[7] "Turbulence and Skin Friction," by Th. von Kármán, *Journal of the Aeronautical Sciences*, vol. 1, no. 1, January, 1934, p. 1.

DETAILED FLOW PATTERN IN A PIPE

This last example is chosen to demonstrate how an appropriate characteristic of the Reynolds-number type may be used for studying in detail the internal mechanism of flow. Instead of bulk values like the average velocity or bulk resistance

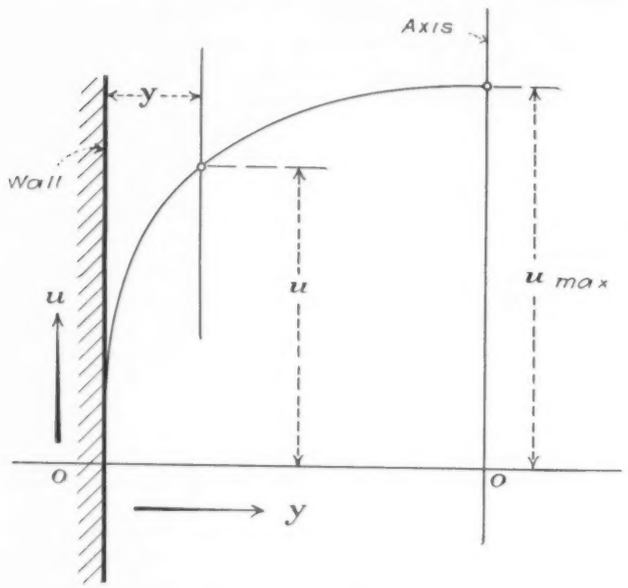

FIG. 10 VELOCITY DISTRIBUTION INSIDE A PIPE

the problem now is to find a law governing the internal distribution of the velocities as well as to establish a rational relation between resistance and the internal elements of flow. Research in this field has recently been amazingly advanced through skillful interpretative experimentation at Göttingen[8] paralleled by theoretical solutions by von Kármán.[9] In seeking suitable terms of reference, Prandtl's suggestion was to refer the motion, Fig. 10, to a special characteristic of the Reynolds number type yu_*/ν, where y is the distance from the wall, while u_* is the so-called *friction velocity*, connected with the average bulk flow by

$$u_*^2 = \frac{\lambda}{8} U^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots [16]$$

and deriving its physical meaning from the tangential stress acting on the pipe wall

$$\tau_0 = \frac{p_1 - p_2}{l} \frac{D}{4} = \frac{\lambda}{4} \rho \frac{U^2}{2} = \rho u_*^2 \quad \ldots\ldots\ldots [17]$$

Fig. 11 represents a logarithmic plotting of the Göttingen experiments on smooth pipes, meaning surfaces where the roughness of the walls has no effect on the internal flow pattern so that the latter is determined exclusively by turbulent agencies arising in the fluid mass itself. The plotted points refer to conduits of widely varying diameters and velocities and naturally to broadly differing friction coefficients. However, when plotted against yu_*/ν the ratios u/u_* follow a unified curve, which in a logarithmic diagram is represented by a straight line. This indicates a logarithmic relation for the law of velocity distribution, which is in accord with von Kármán's theoretical conclusions. In fact the Göttingen experiments lead to a general formula

$$\frac{u}{u_*} = 5.5 + 5.75 \log_{10} \frac{yu_*}{\nu} \quad \ldots\ldots\ldots\ldots [19]$$

supposed to cover all patterns of flow in smooth pipes.

Fig. 12, on the other hand, represents the equation

$$1/\sqrt{\lambda} = 2 \log R\sqrt{\lambda} - 0.8 \quad \ldots\ldots\ldots\ldots [20]$$

which for smooth pipes gives the supposedly universal relation between the resistance coefficient λ and R. As in a smooth pipe the flow pattern is wholly conditioned by internal conditions in the fluid mass, it is entirely proper that the λ value should be fully determined by the Reynolds number. The broken line in the figure corresponds to the earlier well-known formula by Blasius, $\lambda = 0.316/\sqrt[4]{R}$.

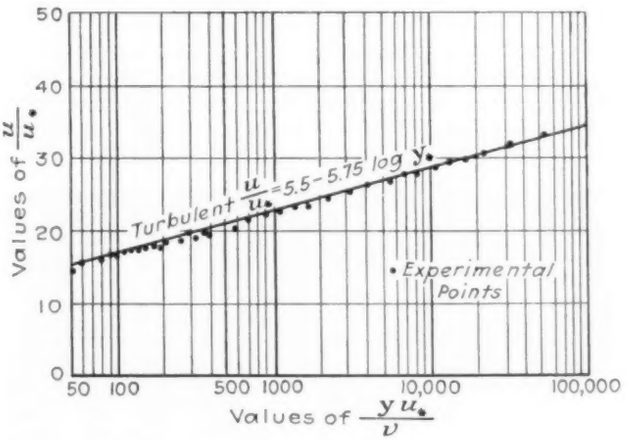

FIG. 11 PROOF OF VELOCITY-DISTRIBUTION LAW (NIKURADZE)

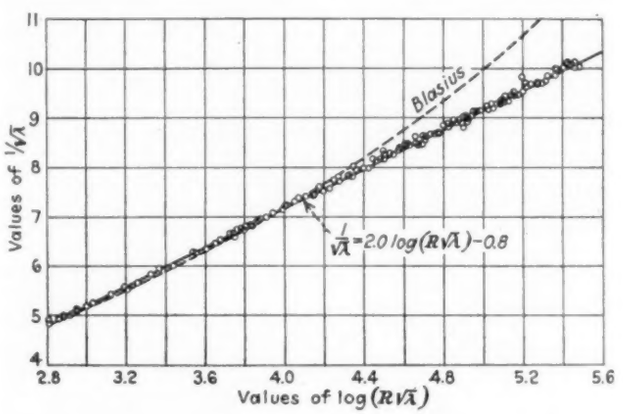

FIG. 12 PROOF OF THE RESISTANCE LAW (NIKURADZE)

One general conclusion seems to evolve from all these examples. The Reynolds number appears to be particularly useful in bridging the gap between the field of purely empirical research and that of theoretical reasoning, a gap so characteristic of hydraulics in the past. In bringing these two realms into harmonic cooperation the trend primarily responsible for the recent progress in engineering science is symbolized.

[8] "Gesetzmässigkeiten der turbulenten Strömung in glatten Rohren," by J. Nikuradse, *Forschung auf dem Gebiete des Ingenieurwesens*, Forschunsheft 356, September and October, 1932. Also "Strömungsgesetze in rauhen Rohren," by J. Nikuradse, *Forschung auf dem Gebiete des Ingenieurwesens*, Forschungsheft 361, July and August, 1933.

[9] "Mechanische Ähnlichkeit und Turbulenz," by Th. von Kármán, Göttingern Nachrichten Mathematische-physikalische Klasse, 1930, p. 58.

PLANNING *for* ECONOMIC PERFORMANCE

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THE REPEATED failures of the general processes of business enterprise both in this and other nations during the past century have been the occasion of many proposals for the reconstruction of our political, social, and economic practices and institutions. The devastating results of the present depression, together with the rapid development of fascist, communist, and cooperative governments in other countries, have given added emphasis to these proposals. It would require a rather elaborate treatise merely to summarize the many suggestions made to cure our present economic ills. In the discussion of many of these points of view one finds repeated reference to the idea of planned economy in substitution for the generally accepted *laissez faire* principle of economic life which Adam Smith popularized in his now classical treatise on "The Wealth of Nations." It was not until the beginning of the present century that the idea of planning and coordinating operations in manufacturing enterprises was introduced. Since then almost all business enterprises have developed planned procedures, not only in their shops, but also in their offices, merchandising methods, and accounting practices. The terms "shop systems," "budgetary control," and "sales forecasting" were not in general use a quarter of a century ago. Today every business of any consequence uses planning methods to coordinate the work of purchasing, processing, and merchandising. It is quite natural, therefore, that the idea of applying the same technique of planning to our national plant as a whole should come under review.

Since this is a civilization in which the engineer has played a prominent part in the creation of wealth and wealth-producing agencies, and in the development of types of organization and management, it is deemed quite proper (except in the most orthodox circles) that he should also participate in the discussions of our national economy. And so this conference of engineers has before it the question of planning for economic performance.

OBJECTIVES OF NATIONAL PLANNING

The subject involves two concepts; planning and economic performance.

The design of a plan to accomplish an economic performance raises the question: What kind of economic performance is desired and in what terms shall it be expressed? Our problem, therefore, begins with the specification of the end results to be attained. It is suggested that a desirable performance of our national economy should accomplish the following results:

1 The most efficient use of nonrenewable material resources such as coal, iron, and gas.

2 The most efficient use, replacement, and additions to renewable national resources, such as the land and its derivatives, wheat, timber, hogs, and cotton. These objectives raise the problems of maintaining and developing physical assets. Much of our so-called prosperity of former days was but the faulty accounting of wasting assets as profits.

3 The growth of the social capital as expressed in the physical, intellectual, and spiritual well-being of every man, woman, and child. This raises the problem of providing those conditions which will assure all persons an opportunity to take part in and contribute to the processes of civilization and culture, and through such participation to derive nourishment for their physical and spiritual developments.

The present processes of civilization have not been operating specifically toward these ends. Our objectives have not been rational because our social philosophy has been faulty. Social conditions are due to social practices and social practices arise from the rules man makes for playing the game of civilization. This game is played by rival teams called private enterprise seeking profit and fortune by hiring for wages the mass of human labor.

Many so-called economic laws which are generally believed to be "natural" laws are no more than the recorded results of man-made processes. They are no more natural laws than the baseball rule "three strikes and out" is a natural law. The entire economic framework in which our business processes are set is wholly man made, and there is nothing sacred about it. We have evolved an economic process for operating the nation's business which is based on a false sense of values and the stockholders of the national plant are wondering if they have not been deceived by faulty accounting methods, because of which the real changes in the values of the national assets are not disclosed. It seems, therefore, that the real objective of any economic planning must be such use of our physical and social capital that their values are at least not impaired and preferably increased for the use of future generations. It is hoped and believed by many that the end result of our present procedure is the general well-being of mankind. Others maintain that it has resulted in the exploitation and depletion of our national resources and social capital and faulty accounting has recorded such liquidation of assets as a net gain.

These differences of opinion warrant a critical examination of our business and social practices to determine what if any basic principles there are upon which a planned procedure for economic development may be founded. If then, the above objectives are to be attained, how can we best organize ourselves for this purpose? Normal social groups are never stagnant. They cannot be contained within a fixed framework of rules and regulations. Thev seek to grow and to attain higher stages of physical and cultural well-being. Abnormal social groups—backward and stagnant races—have, like some individuals, lost the vital forces of the growth processes.

If then we are to have any better organization of our economic processes, the new organization must bear the seeds of its own renewal. It must nourish the vital spark of the life-sustaining processes. By it men must live and live more

An address at the Economics Conference sponsored by the Society for the Promotion of Engineering Education and Stevens Institute of Technology, Johnsonburg, N. J., July 4, 1936. Abridged.

abundantly. Are there any forms of organized life the operation of which we may observe as guides to intelligent planning of an organized procedure? Can we derive a theory of organization from these observations? Regardless of the popular disrepute into which the word "theory" has fallen, it is true, nevertheless, that even the most practical of men plan their actions in accordance with some belief about their future consequences. Such belief is theory. If the belief is well founded in human experience, the theory is good, if not, it is bad. In establishing a planned economy we must first evolve a theory of its operation. We are compelled to base our processes on correct principles of an organized procedure.

A THEORY OF ORGANIZATION

The following theory of organization is believed to be applicable to all forms of organized life from the simplest biological organism to the complex form of social organization found in the modern state. It has been evolved as a result of attempts to answer such questions as: Is the present low state of our national economy due to a faulty pattern of organization? When may an organization structure be said to be ineffective? When may it be said to be effective? What criteria may be applied to estimating the probability of outcome of an organized procedure? Of what elements are organization structures built? Do the same elements appear in all organization structures? If so, how are they embodied, for example, in an industrial enterprise, or a political state?

A study of these and many similar questions has led to the suggestion that all types of organization so far examined are composed of two primary structural divisions which are:

1 Functional equipments by which the organism deals with its environment
2 Integrating equipments:
   (*a*) For external integration, that is, to sense the environment, interpret it, and determine behavior and motivation with respect to it
   (*b*) For internal integration, that is, to coordinate the activities of the functional equipments in response to policies adopted to meet the situations of the environment.

It appears that the following examples support these assertions:

A The biological organism has functional equipments for eating, digesting, moving, and for other responses to its environment and its changes. Its equipments for seeing, hearing, smelling, feeling, and tasting enable it to sense its environment and together with its organized nerve centers to integrate these impressions into a policy of behavior toward it. Thus it is equipped with an *external integrating system* or structural division of organization. Its nervous *system of internal integration* serves to coordinate the activities of its functional equipments by which the organism as a whole meets the problems of its environment.

The growth of the biological organism from the simple unicellular types such as the amoeba to the complex types of animal life, including man, seems to be characterized by two coincident developments; the addition from time to time of specific functional equipments which permit the organism to adapt itself to a wider range of environment and more complete utilization of a specific environment, and the development, refinement, and extension of a nervous system and sensory equipments which serve to give the organism a more complete sense of its surroundings and a greater capacity of adaptation to them. Thus biological growth does not reside wholly in the additions of functional equipments but rather in the proper balance of these with both external and internal integrating systems. The disappearance of certain forms of animal life which existed in the distant past may be explained in terms of the inadequacies of their integrating equipments, their functional organs, or both.

B The *technological process*, such as a power system, is provided with functional equipments such as electric generators, steam turbines, boilers, pumps, heaters, and coolers by which the potential energy of carbonaceous minerals is converted into the dynamic energy of the electric current. While the more complete utilization of fuels has been accomplished by the addition to the system of new and improved functional equipments, these of themselves would never have made the modern power systems possible. As we trace the growth of power plants from their earlier simple forms to the complex interlocking continental networks of today, we find that as the engineer developed larger and more efficient machinery and added more kinds of apparatus to the system, he was compelled to develop, perfect, and install the necessary coordinating and integrating systems which would make it possible for the functional equipments to act in unison and in response to load demands.

Thus the external integrating system of power plants enables them to sense the changes in load demand and meet new kinds of load requirements while the internal integrating equipment controls the balanced operations of the functional machinery.

In both the biological organism and the power system it will be noted that the integrating systems do not possess any arbitrary power within themselves. They must transmit the impulses they receive and do so with absolute fidelity. The external integrating equipments must transmit the sense impressions of the environment and the internal integrating systems must convey the impulses received from the functional equipments without distortion or modification else the whole is thrown out of balance and fails to give a proper response to environmental change. This essential nature of the integrating equipment is important to keep in mind, since it bears directly on the problem of industrial and social development and organization.

C An *industrial enterprise*, such as a company manufacturing furniture or automobiles or food products, operates in an environment the principal divisions of which are raw-materials supply, the consumer market, and the state. It is provided with functional equipments for converting raw materials into products useful to society. But its existence and prosperity do not depend on these alone. It must have adequate external integrating equipment for sensing its environment, its raw-materials supply, the domestic and foreign markets, and the demands of the national, state, and local governments. Its capacity to sense this environment correctly determines in large measure the adequacy of its policies. It must also have a system of internal integration to coordinate the operations of its functional equipments in their response to the demands of the environment. As the processes of civilization became more complex, industrial enterprises not only equipped themselves with larger and more complicated machinery of production, but they were also compelled to refine and extend their systems of integration, in which fields the works of Taylor, Gantt, and Emerson are so well known. Thus the growth of industry is characterized not only by the development of its machinery of production, but also by the introduction of systems of organization and management by which it could use its productive equipment more effectively in the increasingly complex social environment.

D The *social organism*, such as a municipality, a state, or a nation, exhibits the same elements of organization structure.

The modern state sustains itself in its environment by the functional equipments embodied in mass-production factories, cavernous mines, steam-trawler fishing fleets, power-cultivated fields, transcontinental railways, bus routes, airways, steamship lanes, vast banking systems, and national and international merchandising agencies. Not only has society grown by the process of specializing its functional activities and adding to its productive and power equipment, but it has also endeavored to develop, extend, and refine its systems of external and internal integration. It endeavors to sense the environment and its changes by educational systems and news agencies, and by meetings, conventions, and other processes for disseminating information and the formulation of opinions. Its internal integration is attempted through public-utilities commissions, federal trade commissions, statutory laws, trade practices, and social agencies and customs.

Thus these widely different types of organization seem in each instance to be made up of the same structural elements, and their healthy growth is characterized by extensions and refinements of their nervous systems for external and internal integration coincident with the expansions and additions of functional equipments.

CHARACTERISTICS OF GROWTH

It is also interesting to observe that the growths of these organisms in magnitude in time follows the same general pattern. A tree, for example, grows in height, the automobile industry has grown in number of cars produced, and the growth of coal production in time follows the same general trend. The growth of population in the United States has also followed the same trend. One would therefore suspect that each of these forms of organization had control mechanisms for balancing size with environment which operate in a surprisingly uniform fashion. Since such controls appear to reside in mechanisms for external and internal integration one is led to the suggestion that the elements of organization of each type of organism reviewed have the same operating characteristics.

Just as the growth processes in each case seem to conform to uniform laws, so also do we find that each is subject to the same processes of disintegration. When a complex organism breaks down into more simple aggregates it is said to be in a process of disintegration. The biological organism, for example, returns to the earth from which it was formed by processes of disintegration. When the life-sustaining properties which build, maintain, and unite the cells into a complex organized entity disappear, then disintegration into the elements replaces the integrating forces of the life processes.

It appears also that disintegration takes place when the units of the organism begin to feed on the organism as a whole without at the same time making their contribution to the life of the whole. In the processes of healthy growth, the organism as a whole provides the environment from which each cell and each group of specialized cells derive their life-sustaining energy and in return the individual cells and the specialized functional groups each have their part in maintaining the whole in a healthy state. This balanced flow of energy into the cells and from them out to the body as a whole is the life principle of interdependent relationships, of rights and responsibilities by which the life processes are sustained.

The healthy functioning of the technological processes is dependent on the same principles of energy intake and outflow. The fire under the boiler, for example, imparts energy to the shell of the vessel. If an imperfectly functioning shell stores up this energy beyond a certain amount before it is passed on to the water, the temperature of the shell will rise to the point of burning and the whole vessel will be destroyed. Every engineer knows the serious effects of excess energy storage in any part of a power system, a machine tool, or electric generator, or a motor, therefore in the design of such equipments the inflow and outflow of energy is a problem of primary consideration.

The industrial engineer is always concerned with the storage and flow of economic values in industrial enterprises. An excess storage of "values" in fixed assets which do not contribute proportionately to the productive process, or an excess of outflow in dividends which depletes working capital, or the high cost of an overhead service which does not contribute adequately to the effective working of the organization are focal points of disintegration which, if not curbed, may destroy the whole organization. When it is proposed to buy a new machine or add a new department the engineer asks the question, Will it pay? The question, put in other words, is, Will the new cell or group of cells contribute to the growth of the whole or will it absorb more energy from the environment than it returns to it? Will it be a parasite feeding upon and sapping the economic strength of the business or will it do its part in strengthening and rebuilding the environment to higher levels of economic strength?

The social organism also is subject to the same type of disintegrating process. If any considerable number of units derive energy from society as a whole in the form of excess profits, unemployment doles, interest charges, bonuses, excessive salaries, or graft, then there are parts which feed on the whole but do not make a proportionate contribution to the life of the organism. When the lumber industry depletes the forests, the oil industry drains the oil pools, political groups graft on the citizens, or powerful economic groups exploit labor, then we find the processes of disintegration tearing down the complex structure of society and a tendency to form aggregates of dissociated individuals and groups. Thus, in the processes of social growth we find that the environment reacts on the individual to impart energy (physical, mental, and spiritual) to him; the individual in turn rebuilds and refines his environment so that by the action and reaction between the individual and his environment increasingly higher forms of society are attained. When, however, the individual feeds on his environment but fails to contribute to its regeneration, then the unregenerated environment restricts its nourishment of the individual, and decreasingly lower forms of society result. All of these examples of similarity of behavior of widely different forms of organisms seem to confirm the opinion that all have similar structures and principles of operation. We accordingly have reason to believe that the state tends to grow into a more complete realization and embodiment of these principles of organization. If human society ever hopes to fulfill its highest possibilities, it must direct its conduct toward a stimulation of these principles of growth.

THE PROBLEMS OF A PLANNED ECONOMY

The importance of these observations to the problem of a planned economy lies in the fact that if a planned economy is to be successful it must conform in its design and structure to those principles which experience indicates are inherent to successful organized procedures. Accordingly, the plan must be based on

1 An understanding of the operating characteristics of the functional equipments by which society converts the materials of its environment to its needs, and all of the purposes these equipments serve.

2 An appreciation of the fact that the life-giving principle of an organization lies in the excellence of its equipments for

external and internal integration, that is, its nervous system. Society provides itself with its material requirements by its functional equipments for agriculture, forestry, mining, manufacture, and construction. It distributes these through its equipments for transportation, warehousing, and retailing. It facilitates these transactions through its many agencies of money and credit. Its churches, schools, museums, libraries, theaters, and parks serve its spiritual, intellectual, and recreational needs.

If the functional equipments of society are to be maintained in a healthy state so that they can best serve society's needs they must be integrated and their operations coordinated. No sound economic system can be devised on any other principle. No system of government through which planning for economic performance is to be accomplished can be operated successfully in disregard of the foregoing principles of organization structure.

The technical skills with which these many functional equipments have been designed are rightly counted as partial evidence of the growth of civilization. But these industries and institutions serve other than technical functions. They establish the conditions under which people associate with each other, that is, they determine ways of life out of which the culture of the race develops, and they also serve as agencies for distributing the national income, that is, the claims to the goods and services produced. Any plan for better economic performance must also take account of these social and economic functions. We must reorganize the distribution of the national income not only in better and more workable proportions but also as to the ways in which it originates. The functional units of the business process are in a healthy state, individually and collectively, when they operate in harmony with (1) technical, (2) economic, and (3) social principles of interdependent relationships.

The ways in which these functional divisions of social activity, such as manufacture, agriculture, mining, are integrated determine the state of health and vitality of the whole social organism. If our study of the operation of organisms, biological, technical, and industrial, reveals anything it is that the very life of the organism, its capacity to grow and adapt itself to changing environment, its capability of serving the needs of all of its parts, and its ability to resist disintegrating processes, depends on the vital processes of its nervous system. The nervous system of our civilization is embodied in the process of education, all the means employed for learning the truth, and all the methods used for arriving at decisions and formulating the laws and rules by which we live. If we accept the economic and social objectives and the principles of organization structure suggested, how may they be embodied in an operative social system? At this point we face a most difficult obstacle. It is the same obstacle that has retarded the advance of civilization and culture for thousands of years. Less so in recent times but yet a real obstacle. The inability of the mass of mankind to think objectively, the binding fetters of fixed and familiar patterns of action, the inertia of adaptation to new and changed environments, these are the obstacles to social progress as much as they were the obstacles to scientific progress that hindered the work of Harvey, Galileo, and other scientists of former times. Against these men was raised the cry that they were undermining the teachings of the church and defying the laws of God. Today the same cry is raised in the sacred name of the Constitution, of liberty, and of freedom.

Any planning for economic performance must take this fact into account, recognize obstacles, and deal with them intelligently. We must take people as we find them. Any procedure is impracticable in which this fact is not taken into account. The problem now raised divides itself into two main parts—first, setting up a social and economic system which our objective analysis informs us will mean most in social and economic results, and second, devising a practical means of redirecting our present social behavior at minimum social cost. Planned economic performance of any kind is impossible until there are means for carrying out the plan.

Is it too much to expect of mankind that it alter its structure of social organization to make better rules for playing the game of civilization? Are we intelligent enough or are there a sufficient number of enlightened leaders capable of devising proper techniques of social change? My firm conviction is that while the stupidity of man may retard the social organism in its natural tendencies to grow to its destined perfection, it cannot prevent its ultimate accomplishment. Perhaps the present world distress is but the birth pains of a new enlightened age of man.

Synthetic Resins in Varnishes for Wood Protection

(*Continued from page 624*)

It is in industrial and technical coating requirements, such as those just listed, that the varnish industry is today able to offer adequate protection unobtainable a few years ago. The difficult coating problems of yesterday are today being tested and met by finishes of the new type. Such problems as the painting of the interior of oil tankers, gasoline tanks, and the protection of magnesium alloys are being solved. A steel company attacked the problem of painting the interior of steel water tanks. On a one-million-gallon water tank 196 different kinds of coatings were applied for the protection of the steel interior. Each paint was applied in areas more than 24 ft high and 16 in. in width. Every 30 days the tank was drained and two inspectors made independent ratings of the integrity of the coatings. After 571 days the test was completed. The results (9) show that the only finish rating 100 per cent was based on the straight phenol-formaldehyde resin.

It is not alone in clear varnishes but in air-drying and baking pigmented coatings and in nitrocellulose lacquers that the new resins are making fundamental improvements. Through their use the coating manufacturer adds durability, toughness, waterproofness, and resistance properties in addition to quicker finishing schedules.

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DIESEL ENGINEERING INSTRUCTION

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IN 1929 the sale of Diesel engines amounted to about 430,000 hp; in 1935 it was about 1,200,000 hp. Such a spectacular growth coincident with the worst business slump the country has had in several generations inevitably draws attention to the Diesel as perhaps one of the new industries that will miraculously lift us out of the depression. The wide publicity given to the stream-lined Diesel-electric trains and to their splendid performance makes a strong appeal to the imagination of the public. Youth, deprived by adverse economic conditions of the normal opportunity to earn a living, turns eagerly to this new field full of hope that it will furnish the golden opportunity. Groping blindly for a foothold, it is only natural that the thoughts of many should turn to special Diesel instruction as the key that will open the door to opportunity. Fundamentally, we as educators, and you as engine builders and users, must commend such an approach and feel duty-bound to lend every assistance in guiding such efforts along safe and fruitful paths.

The demand for Diesel instruction falls into two rather distinct classifications: (*a*) Special Diesel courses as an integral part of the regular engineering curriculum and open only to students with adequate preparation; (*b*) courses of a more practical nature open to students with only a high-school education, or less, and designed primarily to teach operation, servicing, and maintenance. These will be discussed separately.

COLLEGE INSTRUCTION

In gathering material for this paper I felt that it would be well to make a survey of the present status of Diesel instruction in the technical schools. For this purpose a brief questionnaire was sent to 106 leading colleges in the United States and to 4 in Canada. The response was splendid, 76 per cent, and I am grateful to all those who took the time to answer the questions, and particularly to those who added comments expressing their views on this problem. The first question was: Is there a definite demand for Diesel instruction, (*a*) by students (*b*) by industry? The replies indicate that in 63 colleges there is such a student interest and in 17 there appears to be none; 5 expressed no opinion. As was anticipated, industry is not clamoring for such instruction to any marked degree; in 8 cases there is a definite interest, in 12 some, and in 40 none; 10 did not reply to this question and 9 replied with a question mark which probably means that there is no demand evident. Summarizing, we may say that in 63 colleges there is a definite student interest, in 22 none; that there is some interest manifested by industry in 20 cases while in 59 no such demand has been noted.

COLLEGE ATTITUDE TOWARD SPECIAL COURSES

Any one who has kept in touch with engineering colleges over a period of years knows that there is a constant, even though at times hardly perceptible, evolution going on. They are constantly on the alert to improve their product, which is trained young men prepared to make the most of their chance in industry. To do this the curriculum and the methods of instruction are under constant scrutiny from within, and, I might also say, under constant pressure from interested groups from without for the inclusion of some new specialty that for the moment is in the limelight. Within recent years we have had aeronautics, automobiles, radio, and refrigeration, to mention only a few, and today it is air conditioning and Diesels.

How far should our colleges yield to temptation and to pressure in establishing special courses for undergraduates to meet popular demand? In the opinion of most educators we should be extremely cautious in giving specific recognition to such developments by offering special courses with such titles. Generally, the fundamentals involved are already included, or can be included conveniently, in an existing course. This method makes provision for the necessary basic instruction without undesirable emphasis and without danger of removing the subject from its proper relationship with other parts of a well-coordinated curriculum.

To the college educator the Diesel engine is no novelty; for the past 35 years or more every engineering student of thermodynamics has been taught the principles of the Diesel cycle, just as he has been taught those of the Otto, the Rankine, and the Carnot cycles. It is true, of course, that commercial developments in Diesel construction and application have been extremely rapid during the past few years, but the same thing is true in many other fields, as, for example, in steam engineering. Nevertheless, the amount of time devoted to steam-engineering subjects has in many cases grown progressively less, particularly in such specialized fields as steam-turbine design, which experience has shown is best learned by practice.

The questionnaire already referred to gives some indication of the attitude of the educators regarding special courses in so far as the replies could be fitted to the questions. In answer to the query: To what extent is instruction in Diesel engines given to undergraduates? 29 responses indicate that such instruction is offered as a separate course, is elective in 20 cases, and is required in 9; in 70 cases Diesel instruction is included as a part of a course in internal-combustion engines; this course is elective in 33 institutions and required in 37; 9 replies indicate that Diesel instruction is included as part of an elective course in power plants, while in 36 cases such a course is prescribed. There is some inevitable overlapping in these replies because some institutions require the subject in one curriculum, such as aeronautics, but offer it as an elective for students taking other courses. A surprising result was that only 58 of the 84 institutions include Diesel instruction as a part of a general course in thermodynamics. It seems almost axiomatic that every mechanical engineering course includes thermodynamics and that thermodynamics invariably includes at least the Diesel cycle. Apparently those who

Presented at the Ninth Oil and Gas Power Meeting, Ann Arbor, Mich., June 24–27, 1936, of the Oil and Gas Power Division of The American Society of Mechanical Engineers.

replied in the negative did not think that such brief attention was sufficient to warrant calling it Diesel instruction.

AMOUNT OF TIME DEVOTED

In the third question an attempt was made to determine how much time was devoted to Diesel theory, design, laboratory, and economic problems. The replies are most diverse and are expressed in so many different units that it is difficult to correlate them. In general, however, most time is given to theory, followed by a few laboratory exercises; design and economic problems receive least attention. Laboratory instruction is limited somewhat by the lack of suitable equipment; 60 institutions report having from one to six Diesels each in their laboratories while 12 report no equipment.

GRADUATE INSTRUCTION

With this brief summary we must leave the undergraduate and turn our attention to graduate instruction in Diesel engineering. Fourteen schools offer some advanced courses of this type, which are usually open only to students who have already received the bachelor's degree. The number of courses offered varies from one to seven; probably in no case, however, can a graduate student receive an advanced degree solely by taking special Diesel courses. Related subjects like advanced thermodynamics, mathematics, and mechanics are required, and the advanced degree is usually given in mechanical engineering, the parent subject, and not in Diesel engineering.

It is generally agreed that overspecialization in college is neither desirable nor feasible. The most promising procedure appears to be to limit required undergraduate instruction to a rigorous treatment of fundamental subjects that will be sufficient for the majority of students and will also serve as an adequate basis for advanced work that may be taken by a few. The demand for graduate instruction in a highly specialized field such as Diesel engines is necessarily limited, consequently, few institutions should try to offer comprehensive courses. Students particularly interested should be urged to go to the institution with the most competent staff and the best facilities.

The survey also shows that approximately 4000 undergraduates and 115 graduate students are each year receiving some instruction in Diesel engineering in the 84 schools that replied.

NONCOLLEGE INSTRUCTION

"If the people cannot come to college it is our duty to take the college to them," was the slogan of the head of one of our large land-grant colleges during the period that agricultural extension and county farm-agent work were being built up. Extension evening classes and correspondence courses administered by some colleges and universities in various technical subjects have in many cases been invaluable in providing opportunities for adult education. The evening extension classes, taught by specialists in the subject, are outstanding and, when there is a large enough group to warrant forming a class, are much superior to correspondence courses. A modification of this is the short course in Diesel engines and tractors such as is offered each year at Montana State College. The course lasts 10 weeks and "is intended to give training to those men who have the mechanical ability and the desire to become efficient in engine and tractor operation and maintenance. The course is based on the assumption that the student is sufficiently mature to learn the principles of engines and use them in his work, that he is mechanically inclined, that he has had experience with machinery, engines, and autos, and that he will make practical use of his training in his work." This year the course was given to 38 full-time students for 10 weeks and to 15 night-school students. The instruction fee for the 10 weeks' course was $25.

PUBLIC-SCHOOL COURSES

We must again turn to Montana for the initiative in another phase of Diesel instruction. This year the public schools of Butte, Montana, gave a Diesel-engineering course as a part of their federal-aid Smith-Hughes program which was open only to men who actually needed that type of instruction on the jobs that they were doing. Ninety-four men were enrolled in afternoon and evening classes and each student was given 27 hours of instruction. The only educational qualification was that the person desiring admission be certified by some labor union as qualified as an engineer or mechanic. The instruction was of a practical laboratory nature with two instructors working with about 20 men at a time. To help defray the cost each man paid the modest sum of $10.

It is obvious that instruction of this kind in no way overlaps that given in college courses. Colleges should provide the rigorous training in fundamentals that will qualify the student to go into design, research, and production and a minimum training in operation and maintenance. On the other hand, trade, vocational, and extension courses make no such exacting demands on the student's intellectual ability; they are primarily designed for teaching operation, maintenance, servicing. The latter instruction is valuable in direct proportion to the previous mechanical training and ability of the student and the subsequent opportunity he may have to use the knowledge gained. Instruction of this type is relatively new but is sure to grow as the Diesel industry develops. Because of the relatively low cost and because they furnish practical information directly to the man who can make immediate use of it, these courses have much to commend them.

SPECIAL DIESEL SCHOOLS

America has long been regarded as a land of boundless opportunity where a man's success is limited only by his initiative and resourcefulness in getting what he wants. This ambition has opened the way in every new development for special schools to offer instruction of varying degrees of excellence, sometimes for the benefit of the student but more often for the enrichment of the promoter. The Diesel is no exception. While a few of these schools are adequately equipped and capably staffed and are honestly rendering satisfactory service in a limited field to their students, many are not and, judging from comments received, it would seem that for the good of the industry and the protection of the public they should be suppressed. This situation is not unique. Even the United States Civil Service Commission finds it necessary to post conspicuously in post offices a detailed announcement warning the public that the claims made by some special schools regarding positions in the civil service are misleading and not based on facts. In the language of the street they are branded as "rackets."

The chief criticisms of the special Diesel schools are weak or inefficient teaching staff, inadequate equipment, and unethical sales methods used for obtaining students. The first two points need no discussion; the last has proved a pitfall for the unwary. The methods of attracting students are varied—advertisements in newspapers both local and national, direct-by-mail letters, personal sales interviews, and radio announcements. Certainly this publicity has helped make the public Diesel-conscious and for that we should all be grateful. Too often, however, the prospective student hears only of wonderful opportunities and about the students who have been successful. With visions of his own success he signs a contract obligating

him to pay several hundred dollars for a mediocre course of instruction. Some of these youths are not fitted for this work, and when they come to their senses and realize the situation they find to their sorrow that they cannot avoid paying the fee, whether they continue the course or not.

CONDITIONS IN HEAVY-DUTY DIESEL INDUSTRY

Let us look further and see to what extent the promise, either direct or implied, of a good job for these students can be fulfilled. While the Diesel growth has been rapid in the past few years it should not be forgotten that production is still small compared to that of its competitors. The heavy-duty Diesel has been a factor for many years in power plant and marine installations. The industry is highly competitive with the steam and hydroelectric and slight variations in cost of fuels or first cost of machinery will often determine the selection of one kind or another. This branch of the industry has been well stabilized for some time and it is unlikely that there will be many opportunities for new jobs in this branch in the immediate future. According to a survey made by the National Industrial Conference Board in 1933 of the conditions in 21 companies manufacturing heavy-duty Diesels the number of men employed in 1929 was 6556 and only 2743 in 1933; the average hourly wage per skilled workman during the same time had dropped from 70.3 to 58.7 cents and the weekly wage from $34.26 to $22.90. These figures should refute conclusively any unfounded statements about the high pay of Diesel mechanics. It also follows that average operators of Diesel engines cannot receive much more than these amounts, otherwise all competent mechanics would leave the employ of manufacturers and take jobs operating Diesel plants.

Where a Diesel engine replaces a steam engine or purchased power, the owner already has a trained operating personnel with power-plant experience who can be trained in a few weeks in new duties by the engine builder's representative. Most of the brand new plants are those being built by municipalities. Here new talent is often required, but it is easy to see that a home-town voter is almost sure to get the job if he can possibly qualify and again the engine builder is usually glad to give all possible help by employing him during erection and training him during the initial operating period.

CONDITION IN HIGH-SPEED DIESEL FIELD

The other main division of the Diesel industry is the high-speed automotive field, and it is this branch that is responsible for most of the "ballyhoo" publicity of the past few years. These units are finding wide application in trucks, tractors, buses, shovels, road-building machinery, and small isolated plants. Five years ago this branch of the industry was in the development stage; in 1935 it accounted for approximately three-fourths of the total production of 1,200,000 hp. Phenomenal as this growth has been it is likely to be even more spectacular in the immediate future because the Diesel's competitor in this field, the gasoline engine, is comparatively inefficient. To the casual observer this might indicate a vast new field for new employees with special Diesel training. However, this is not the case. From the manufacturer's standpoint this is not *new* business but a substitution for gasoline engines. The increase in Diesel production represents a corresponding reduction in gasoline engines. The manufacturing problems are essentially similar and few if any new mechanics are required.

The operation of tractors, trucks, buses, and other Diesel-powered equipment does not differ in any way from that of similar gasoline equipment, and it is often immaterial whether or not the operator even knows what kind of unit he is using. Maintenance and repair of this equipment may furnish an opportunity for some new men, but again it should be stressed that this is not new equipment and that in most respects the present automotive service stations can take care of the work. There has always been and probably always will be room for the exceptionally skilled automotive mechanic regardless of whether he services the gasoline or the Diesel.

NO VAST NEW FIELD OF EMPLOYMENT OPEN

The conclusion seems inevitable that the Diesel does not open up a vast new field of employment either in manufacturing, operating, or servicing, and that the rate of pay is not substantially greater than in other similar lines of work. These facts cannot be emphasized too strongly. The literature of some of the special Diesel schools is so cleverly worded that the casual reader is quite likely to get just the opposite idea and without full investigation and proper guidance enter into a contract for a course for which he is not fitted and to spend time preparing for a field in which he cannot possibly succeed. Fortunately, not all of these schools are guilty of such unethical practices; some of them give the prospective student a fair picture of the opportunities and of the rewards that may be won only by ability and by hard work. Such schools fill a real need in providing suitable training for ambitious young men who cannot and perhaps should not go to college and who are not able to take an extension, vocational, or public trade-school course. The cost of the special Diesel courses and of other incidental expenses, such as board and room, is high and the benefits rather problematical, therefore the prospective student should be cautioned to consider carefully whether the school is properly equipped and has an adequate staff of competent instructors to give him necessary individual instruction.

For students who cannot attend in residence, some of these schools also offer correspondence courses, sometimes in combination with a short period of shop instruction on the completion of the correspondence work. Correspondence courses, if properly conducted, have the merit of being directed study with some supervision through the correction of the lessons by a member of the staff. Cases of flagrant violations of good correspondence instruction have been reported. For example, one widely advertised school is said to ask examination questions on a "true and false" basis, for instance, "Is it true that a four-cycle engine has one power impulse per cylinder per two revolutions?" Such courses have no value and require no intelligence on the part of the examining staff and little from the student. Before signing up for a correspondence course the student should consider carefully the alternative of buying a few standard books on Diesels and subscribing to some of the leading periodicals in the field. The cost will be much less than the tuition fee charged for the usual correspondence course and the results fully as good. At best, courses of this kind are comparable to what the colleges call "survey" courses; they are informative and perhaps adequate for any one needing only a casual knowledge of the subject, but they alone cannot produce an expert Diesel mechanic, operator, or designer. No one is likely to offer the "graduate" of one of these courses, either correspondence or residence, a job with big pay just because he has taken the course, but if he has ability and an opportunity does come the knowledge he should get from such instruction should be helpful to him.

In conclusion, the Diesel has passed its infancy and is rapidly assuming its place as one of our important industries. There will be increasing opportunities for graduate engineers with specialized Diesel training and for skilled mechanics with some knowledge of the underlying principles. The opportunities and the compensations are comparable to those in similar lines.

SPECIAL CASES IN DEPRECIATION

By WILLIAM D. ENNIS

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CASE I

A MANUFACTURER puts $1,000,000 of his own money into plant and equipment having an estimated life of 30 years. A superorthodox individual, he is not satisfied with an accrued depreciation account, a mere segregation of surplus, but determines to withdraw cash for investment in a trust fund to assure replacement after 30 years. At 3 per cent the necessary annual charge to depreciation expense is $21,000. Or, he might invest $412,000 at the time of construction. This, at 3 per cent, would become the $1,000,000 needed for replacement (ignoring changes in construction cost) after 30 years. But, theoretically, he will need a new plant every 30 years *forever*. If he wishes to cover this perpetual replacement program by one lump sum, he must set aside for investment now that amount X which will become $\$1,000,000 + X$ at the end of 30 years. At 3 per cent, $1 becomes $2.427 . . . . Hence $X = \$1,000,000 \div 1.427 \ldots = \$700,000$. The investment of $1,700,000 provides: Initial plant and equipment, $1,000,000.

Invested cash, $700,000, which grows to $1,700,000 in 30 years. Then $1,000,000 may be expended on property replacement, the remaining $700,000 continuing to grow for the next 30 years, and so on. Only 10/17 or 59 per cent of the total original investment would be immediately expended.

This is the case of *ownership capital*.

CASE II

Consider the case of *creditor capital*. A municipality does a paving job at a cost of $1,000,000. The expected life is 30 years. All the money is borrowed. No depreciation is charged. Sinking-fund bonds are issued to those who furnish the money, yielding 3 per cent and maturing in 30 years. The amortization sinking fund is $21,000 yearly. (A better result might be realized with serial bonds of appropriate maturities.)

Again, a single investment, now, of $412,000 would at 3 per cent provide for repayment of the debt at maturity.

Interest must be paid in addition. It is other peoples' money which is being used.

Why are any charges for depreciation necessary? At the end of 30 years, the paving will need replacement, and there will be no money with which to replace it. But this was the precise condition existing 30 years earlier. The city must borrow, as it did then. The original conditions have been restored, as they were restored in case I.

CASE III

Passing the point that in case II the funds should not have *all* been obtained by borrowing, it may be noted that case I is exceptional. The manufacturer usually borrows part of the $1,000,000. Railroads, for example, borrow about two thirds of total capital. Hence the practical case with a private corporation more nearly resembles case II than case I. In so far as there is creditor financing in perpetuity (again a railroad characteristic), and if sinking-fund or serial bonds of proper term are issued, the latter not too much differing in maturities from the time-value relationship of the property itself, there seems to be no justification for depreciation. Depreciation charges related to ownership equity only would seem to satisfy the conditions.

CASE IV

In the case of endowments, we must think of something which is neither ownership capital nor creditor capital. Endowed institutions rarely charge depreciation. This leads to some interesting variant cases.

CASE IV *a*

A donor conveys $2,000,000 to a school, half to be used for land and half for buildings. No depreciation is charged. After 30 years, the location has become more urban, costs of operation have greatly increased, and the trustees are considering a new site. The land has appreciated somewhat, but the market value of the whole property is now only $1,200,000. The buildings are useful only for school purposes, and that is the very use in which the land has little value. If the school moves, it must buy land and erect new buildings. Suppose that these would cost, as before, $2,000,000. Then $800,000 must be found. This offsets the saving in operating costs which is anticipated from removal. A proper depreciation policy would have forestalled this.

CASE IV *b*

Such a donor usually (although not always avowedly) contemplates the perpetual use of the property conveyed. This is an unsound assumption. If the conditions were as recited, he should have given for the building not $1,000,000 but $1,700,000. Giving the former amount makes his gift conditional, not absolute. He is offering to give $1,000,000 if the trustees give $700,000. They did not realize their obligation to find $700,000. Hence their present difficulties. When a gift is made for physical equipment (exclusive of land), not over 60 per cent (in general) of that gift should be spent on immediate construction. The remainder should be invested as a renewal fund.

CASE IV *c*

A wealthy benefactor gave $1,000,000 to a group of four benevolent enterprises, conditional on their furnishing the land. The beneficiaries incorporated to acquire land and construct the building. Each paid a competitive rental to this corporation for the respective spaces occupied, and there was some other rental income. As an offset, they received dividends on their equities in the property. Although there is no tax or interest expense, costs have risen, and now, after 30 years, net rentals paid are about in line with those paid in commercial near-by buildings. This is in spite of the fact that inadequate depreciation charges are being made. The enterprise should have started with benefactor contribution (building), $1,000,000; beneficiary contribution (land), $1,000,000; replacement endowment, $700,000. Had this been done, the last item would by now have grown to $1,700,000, $1,000,000 of which could have been used for modernization. Or, removal to a new site would be practicable. Failure to provide the $700,000 endowment could have been offset by regular annual depreciation charges of $21,000.

The only constant thing is change. One who aims to give for future generations must provide not merely the thing itself but also provide for change and decay and resulting renewal.

SPRAYING *of* MOLTEN METAL

By L. E. KUNKLER

METALLIZING COMPANY OF AMERICA, LOS ANGELES, CALIF.

METALLIZING, or the spraying of molten metal, is a process for spraying pure metals on any metallic or nonmetallic surface without the use of flux and without preheating the object to be coated. The putting-on tool is a small gun weighing $3\frac{1}{2}$ to 5 lb. The gun embodies within its small dimensions a power plant, which draws the wire through it; a miniature foundry, fueled by oxygen and acetylene gases, which melts the wire; and a projector actuated by compressed air, which quenches and atomizes the molten metal and blasts it at a high velocity and with tremendous force onto any object at which it is aimed. Its purpose is to stop corrosion and offset the effects of abrasion and erosion. In the last few years its value has been proved by its wide-spread adoption for restoring machine parts to original dimensions.

Because sprayed metal has a low tensile strength and a high compressive strength conditions under which it is used must be considered. Sprayed metal is brittle. Coatings should never be applied if the material is to be bent or rolled after spraying.

The low tensile strength and brittle characteristics of sprayed metal seem to result from the manner in which the coating is built up, which gives only a mechanical instead of a fusion bond, and from the oxide that is introduced by spraying. Formerly, there was considerable oxide in the coating, particularly on shafting where the procedure was to apply one coat and then go back and forth over the surface, depositing 0.0015 in. per coat, with a total of 50 or 60 coats. There would be a little oxide between each coat. The newly developed and recommended technique is to apply the coating on a shaft with one traverse of the gun across the surface. At one traverse as much as $\frac{1}{2}$ in. on a side can be deposited at one coating. A large percentage of the oxide produced by the former method is eliminated. All deposits are the same as cast metal, look the same, and must be machined or ground, depending upon the hardness of the metal deposited.

PREPARING THE SURFACE FOR METAL SPRAYING

Two methods of preparation are possible; sand or steel-grit blasting and rough threading. On flat surfaces, such as tanks or structural-steel members, blasting is the only practical method of preparing the surface, and for this a sharp, angular grit or sand must be used. The sharp grit or sand will make a jagged surface to hold the metal, while a round sand will peen it. Blasting can be used to prepare shafts, but there is danger that the mechanic will put his hand on the blasted surface and thus get dirt, oil, or other foreign substances on it, which in turn would weaken the bond. A practical procedure is to cut a rough thread on the surface.

One manufacturer is putting a stainless sprayed-steel insert 6 in. long in his pump rods. The rods, $1\frac{1}{2}$ in. in diameter, are placed in a lathe and one cut, $\frac{1}{32}$ in. deep, is taken on the full 6 in. Then a pointed tool is used to dovetail each shoulder at the end of the cut. The dovetail must go into the shoulder about 0.010 in., and this extra metal on each end will eliminate cracking of the coating. A V-tool is used to make a rough thread, 16 to 18 to the inch, on the surface to be sprayed with metal. Threading with the lathe in back gear tears the surface and leaves an ideal anchor for the sprayed coating.

When it is necessary to apply a coating at the end of a shaft, the procedure is to undercut the surface, starting from the end of the shaft, toward the center. A dovetail under the shoulder that is left on the shaft anchors the edge of the coating. The surface must be rough-threaded, followed by spraying the coating to the end of the shaft. The undercut of $\frac{1}{32}$ in. will not affect the operation of the journal or the bearing and will eliminate any chance of cracking at the end of the coating. On large-diameter pump rods brazing of the end is resorted to particularly on worn shafts where it is impossible to dovetail.

COMPARISON OF METAL SPRAYING WITH WELDING

The metal-spraying process is superior to welding for building up machine parts since no preheating is required, nor is overheating developed during the operation. Warping or distortion is impossible. No internal stresses are set up, and danger of crystallization is eliminated. Although, the bond secured is strictly mechanical, and is in no way a fusion bond such as is obtained by welding, if it is made as outlined in the foregoing procedure, it is adequate.

A shaft or pump rod can be restored to original dimensions by the metallizing process in less than half the time necessary for welding. It has the added advantage that a sprayed coating possesses a uniform hardness without the hard and soft spots usually encountered in arc welding. The grinding or machining time required on sprayed coatings is half that required on a welded coating, because the sprayed metal is evenly deposited, while in welding the metal is deposited in the form of beaded rings.

By the metal-spraying process, any metal can be deposited. Surfaces can be restored to normal at a cost 50 to 100 per cent lower than in welding and there is no distortion. The sprayed coating may be harder and tougher than the original shaft or the surface obtained by welding. It will resist from $1\frac{1}{2}$ to $2\frac{1}{2}$ times as much wear as will the original shaft. The air-quenched sprayed metal is 35 per cent harder and possesses a grain structure that absorbs lubricants that maintain a protective oil film on the bearing surface.

WEARING QUALITY OF SPRAYED SURFACE

Many oil companies and oil refineries have made a close check between the wearing qualities of sprayed high-carbon-steel rods and those of a solid steel rod. In a test of the lasting qualities of sprayed fluid-end piston rods in comparison with new rods, two rods were sprayed with high-carbon steel and two were new rods. One new rod and one sprayed rod were placed in each pump. A stroke counter was attached to each pump. After 121,319 strokes of pump No. 2 the metallized pump plunger had worn 0.0030 in. and the new pump plunger had worn 0.0064 in. Pump No. 1 showed comparable results.

In considering the effects of the expansion and contraction of different metals it might appear at first that the application of metal-sprayed coatings would be limited where a large range of temperatures was to be encountered. This, however, is not so, as the structure of a sprayed coating is not as dense as the solid metal on which the coating is being applied and therefore

Contributed by the Machine Shop Practice Division and presented at the Semi-Annual Meeting, Dallas, Texas, June 15–20, 1936, of THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS. Abridged.

has a certain "give." It also happens that desirable applications bring together metals whose coefficients of expansion are similar and the conditions under which the applications must work are such that there is no great temperature change between the base metal and the sprayed coating. Failures from such a cause are so rare that I have heard of none.

GRINDING AND MACHINING METAL-SPRAYED SURFACES

In finishing metal-sprayed surfaces, wet grinding is the most desirable method. Dry grinding does not produce the polished surface desired for bearing surfaces and it is difficult to maintain finished diameters due to wear of the wheel. Practically all metal-sprayed coatings can be machined. Some machine beautifully and others cannot be machined to give a fine finish. Much depends on the composition of the metal. Ordinary brass or bronze will not finish with the smoothness required for some classes of work, whereas a tobin-bronze coating machines like a solid bar of this material. All steels, with the exception of high carbon, can be machined readily, but wet grinding is preferable where a fine finish is desired.

The approximate scleroscope hardness of sprayed metals is as follows: Bronze 18, phosphor bronze 26, 0.10 carbon steel 26, 0.40 carbon steel 40, 0.80 carbon steel 60, 1.20 carbon steel 75, Metco No. 1 stainless steel 45, Metco No. 2 stainless steel 70.

BOND STRENGTH

Tests have been made to determine the bond strength of sprayed coatings on flat surfaces. In these tests a mild-steel rod, 1 in. in diameter, and a crosspiece of steel 6 in. long, $1^1/_2$ in. wide, and $^1/_4$ in. thick were prepared. A hole was drilled in the crosspiece and machined to a size slightly larger than the diameter of the rod. The hole was made large enough so that friction between the rod and the crosspiece could be neglected, and small enough so that no sprayed metal could get between the rod and crosspiece.

Both the crosspiece and the end of the rod were carefully sandblasted. The rod was then inserted in the hole of the crosspiece, with the end of the rod flush with one surface of the crosspiece. The rod and crosspiece were held rigidly in this position while the surface of the crosspiece and the end of the rod were sprayed with metal. When the test piece was properly sprayed, it was placed in the tension machine, and loaded until the rod pulled away from the coating. The average bond strength of various metals so tested was 700 lb per sq in.

No exact procedure has been adopted for the testing of bond strengths on shafts, although W. E. Glidden worked out a procedure by which he claims to have observed bond strength on shafts as high as 12,000 lb per sq in. In our opinion this value is rather high, but we know that it is difficult to break a shaft coating by pounding or hammering.

VARIOUS METAL-SPRAYING JOBS

Metal-spraying equipment is widely used for spraying copper onto carbon brushes and resistors, thus replacing the older method of plating; for spraying zinc on radio tubes; for spraying zinc on steels; for spraying aluminum on the interior surface of pressure vessels to retard the action of hydrogen sulphide; and for spraying various metals for decorative purposes. Its most important field, however, is general maintenance by coating machine elements.

Worn machine elements such as spindle bearings, lead-screw bearings, bearing housings, press fits, tapers, oversize boxes, undersize shafts, pump plungers, pump lines, pump spindles, crankshafts, countershaft bearings, pistons, and a host of parts too numerous to mention can be economically restored to original dimensions for a fraction of the cost of replacement with new parts. Coatings can be applied that will resist wear or corrosion, or both. The savings possible are obvious when the cost of stainless steel or monel-metal shafts is considered as compared to the cost of shafts made of machinery steel and coated with stainless steel or monel metal to a thickness determined by the permissible amount of wear. It is common practice to repair worn armature shafts by building them up with high-carbon steel. This operation is simple and does not require the removal of the windings or the commutator. As armature shafts are not made of high-carbon steel, the additional wear-resisting quality obtained by metal coating is evident. The adoption of this method eliminates handling odd-size bearings and the expense of tearing down the shaft and fitting a sleeve. The cost of metal coating in this instance is far less than that of either of the foregoing alternatives.

Shafts that have been hardened cannot be built up in their hardened state; and this holds true of shafts that have been so built and hardened that the surface of the shaft constitutes the inner race for a roller bearing. Metal-sprayed coatings have ample strength when used as a bearing surface in a sleeve bearing, but due to the structure of the coating, sprayed surfaces should not be used for races for ball or roller bearings.

A metal-spraying job that was done in 1933 and is still in service today is of interest because of its highly satisfactory record. It was the building up to original dimension of a steam-turbine shaft. This machine has a speed of 3600 rpm, is subjected to from 50 to 750 F and is in operation 24 hr per day. A stainless-steel coating was applied to the surface of the shaft without dismantling the machine. This simple operation saved the owners more than $5000. The work was done in February, 1933, and since that time scores of other operators of turbines have built up journals by metal spraying.

In another job six connecting-rod and seven main bearings of the crankshaft of a Waukesha motor were built up with 0.80 carbon steel. Since this work was done in 1933 the motor has been driven 160,000 miles. The shaft has been inspected and measured and less than 0.00025 in. of wear has been observed Copper-lead bearings were used.

On a Canadian railroad a much needed locomotive was tied up in the repair shop because the cylinder replacement sleeve that had been shipped was 0.006 in. undersize. A press fit was necessary. The master mechanic called on a local machine shop that was equipped to do metal spraying. The liner, 40 in. by 24 in., was too big for the lathe and the 0.006 in. of metal was to be applied to the lower half of the cylinder only in order to press the valve ports tight against the top of the walls. The surface was carefully steel blasted. Low-carbon steel was applied with good dead reckoning as to the quantity, and the cylinder was successfully installed the same day without machining.

Another recent job of metal spraying was on a 4-in. shaft in a large dredging machine. The shaft had worn considerably and was badly scored in several places so that it was necessary to install a new shaft. It was found, however, that it would take three weeks to obtain the shaft and that it would cost $750. Time was a matter of great importance. By means of metal spraying, 60 lb of 1.20 carbon steel was applied and the total elapsed time was just under six hours.

The life of a pump shaft is determined by two factors, the corrosive action of the water being pumped and the pressure necessary on the packing-gland area to offset the fluid pressure. When a shaft is treated with stainless steel at the gland area corrosion losses are eliminated. This, in turn, materially reduces pressure and friction, and will more than double the life of the pump shaft. It is therefore more valuable than the new shaft as an alternative. It also saves dismantling the pump.

STREAMLINING THE DISMAL SCIENCE

By JOHN SHUTE

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OUR economic system is an evolving organism rather than the formalized product of a dogmatic economic theory. So it is, then, that in place of the hierarchy of infallible official interpreters which characterizes the totalitarian state, we have a throng of critics whose jeers, lamentations, catcalls, and side-line advice more or less guide our political economy in its wobbly path. When books such as Mordecai Ezekiel's "$2500 a Year,"[1] fail to appear, then we will know that the twilight of free capitalism is at hand.

To the superficial observer the subtitle of Dr. Ezekiel's book, "From Scarcity to Abundance," may seem somewhat extravagant, but when we consider that in the roseate days of 1929, 71 per cent of the families in the United States received an annual income of less than $2500, then we realize that abundance is truly relative.

Unlike most native proponents of economic panaceas, Dr. Ezekiel is an economist and a statistician of repute. Because of his training he is careful to point out that we cannot achieve the desired goal by some fantastic scheme to "share the wealth" or by spectacular monetary legerdemain. We have not and never have produced enough to provide even an *average* yearly income of $2500, to say nothing of a minimum income of this amount.

However, studies by the Brookings Institution and others have shown that we have the physical capacity to provide this minimum standard. Our present factories and farms, our railroads and power plants, when geared up to capacity speed, could more than meet this objective. We are, as some happily nameless phrase-maker has said, confronted with the paradox of poverty amidst plenty. It is clear, then, that Dr. Ezekiel's claim to our attention does not lie in the exposition of our dilemma; in this, and even in his attempted explanation of why scarcity continues he is but one of a long line of popular and semi-popular economic apologists. The depression economic literature is rich with lucid accounts of the growing inflexibility of our theoretical system of competitive free enterprise. Stuart Chase, Sumner H. Slichter, and Walter Lippmann, among the popular group, have all expounded the thesis that wages, prices, labor, and capital do not respond sufficiently fast because of the complex nature of our machine-age system of production and distribution. Because of this inflexibility Dr. Ezekiel believes the classical economics of Adam Smith, Ricardo, and Mill is obsolete and cannot operate under present-day conditions.

It is indisputably true that prices are inflexible, that labor is not perfectly mobile, and that capital is slow-moving. Monopoly, utility-rate fixing, union-wage scales, and catalog prices are all evidence to support his theory. It does seem, however, that in many respects the machine age has tended to increase the flexibility of the national economic system. The telephone, the radio, the motor truck, all the modern devices for rapid communication and transportation must have increased this flexibility in areas which would have startled the older economists. It is questionable if the machine age has not substituted but one form of inflexibility for another.

It is not only classical economic theory in practice which Dr. Ezekiel distrusts; he vigorously denounces the profit motive, although rather inconsistently retaining it in his final scheme of salvation. He says, "Our present economic system, inherited from the past, tends to obscure the simple physical aspects of the problem. By centering attention on making money, it distracts us from the primary importance of making more goods and creating more services." In view of American mass-production methods, and the high-pressure business-expansionist doctrines which characterized the golden era, such criticism seems unduly pessimistic. However, it is in the suggested cure rather than in the diagnosis that Ezekiel displays the greater ingenuity, and the larger part of the book is devoted to an explanation of this cure.

If we are to raise our national product to the high level proposed (about 40 billions above the 1929 figure) then the various contributing factors must be coordinated and an integrated plan of expansion developed. The author explains how this might be done, and then proceeds, in an extremely interesting and lucid manner, to outline just such a "blueprint" for the more abundant life.

From several earlier studies he produces data to illustrate how the new higher incomes would be expended. After compromises and readjustments of potential consumer demand to immediate productive capacity, he is able to sketch broadly the extent of expansion which would be necessary in various fields. House-furnishings production would be stepped up 52 per cent, automobile and transportation up 28 per cent, etc.

Having proposed his standard and having calculated the necessary increases in the volume of production, Dr. Ezekiel goes on to explain how this economy of abundance might be achieved. First he offers the method of voluntary cooperation of business men. Because of conflicting self-interests and the difficulty of successfully compromising the widely divergent desires of various groups within the business system, he believes it would be extremely difficult even to formulate a satisfactory "blueprint" voluntarily and if formulated, impossible to put into practice.

After disposing of voluntary cooperation, Dr. Ezekiel suggests a second possible means of reaching the desired end—that of public underwriting of production. Under this scheme the federal government would guarantee manufacturers a market for their greatly increased production. The difficulties of this plan are only too obvious. Even with the usual degree of political chicanery the expense of underwriting the production of diversified industries according to agreements reached under the influence of high-pressure lobbying would be fantastically high.

The author's third proposal is more stimulating and seems worthy of deeper consideration than he gives to it. By what he terms "yardstick competition" prices might be lowered and production increased. This yardstick competition would take the form of government-owned enterprises which, when efficiently operated, and making due allowances for the economic advantages of public ownership, would stimulate private enterprise to the desired productive level. The experience of govern-

[1] "$2500 a Year. From Scarcity to Abundance," by Mordecai Ezekiel. New York, 1936, Harcourt, Brace, and Company, 328 pp., $2.50.

One of a series of reviews of current economic literature affecting engineering prepared by members of the department of economics and social science, Massachusetts Institute of Technology, at the request of the Management Division of THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS.

ment-owned electric power plants in forcing down rates offers considerable evidence as to the effectiveness of this method. Indeed, in some cases the mere threat of public ownership has been sufficient to cause a general lowering of rates. Dr. Ezekiel points out that in this case a blueprint might not be needed and that a frontal attack on such obvious monopolies as steel and aluminum would do much to bring about the desired result. Of course the difficulties of getting such a plan in action are at once apparent. The powerful objections of big business, fearful of even minor encroachments of government into what it considers the legitimate field of private enterprise, would probably be sufficient to prevent the realization of such a scheme. The author believes the constitutional obstacles might be overcome by the device of government-owned co-operations.

Dr. Ezekiel's final method of achieving blueprint production standards is by means of what he calls "industrial adjustment." According to this plan benefit payments would be made to manufacturers meeting certain requirements of wages, prices, and volume of production. It is of course the A.A.A. applied to industry. By varying benefit payments to industries it would be possible to achieve the balanced expansion set forth in the blueprint. The cost of the benefit payments would be met by a tax on production, so that a manufacturer would pay even if he refused to cooperate. By this means "voluntary" cooperation would be assured.

The administrative difficulties of such a plan would be tremendous, although in the light of the experience of the A.A.A. they might not be insurmountable. Some flexibility could be introduced by varying the payments to meet changing conditions which might develop as the ideals of the plan were realized. Dr. Ezekiel gives some hint as to how the administrative machinery could be organized. He would have decentralized administration, allowing the various units considerable authority and responsibility.

Since the book was written before the A.A.A. decisions of the Supreme Court, it is pointless to discuss the constitutionality of the proposed industrial-adjustment plan. The necessary legislation would undoubtedly not meet with Supreme Court approval and it would be difficult to produce a convenient "conservation" program to evade the inevitable decision.

As in the case of the yardstick competition plan, the impact of the disapproval of big business would probably prevent the scheme from reaching the legislative state.

The economic objections to an industrial adjustment program are of course obvious to Dr. Ezekiel. It poses most of the problems of socialism and offers few of the advantages. We would be confronted by the overwhelming problem of setting prices and regulating production almost arbitrarily. The author is disturbed by many of these aspects of his plan and points out the dangers of rigidly regulating prices and production. Conceivably, innovations might be stifled and technical conservatism placed at a premium. It is inconsistent of the author to damn the existing economic order for its inflexibility and then as a remedy offer a different brand of inflexibility.

Like so many other of the proposed general solutions of our economic woes, Dr. Ezekiel's book fails to recognize that the advantages of the capitalistic system are those which are peculiar to it. An emasculated capitalism would probably be much less desirable than a vigorous socialism.

To many it must seem that the way out of our dilemma does not lie in furthering the breach between the economic theory under which we pretend to live, and the economic system under which we operate. It may be that when the inventors and engineers turn from applying their innovations to the physical sciences and instead apply their efforts to the social sciences, the test of capitalism will come. When the genius which went to the creation of the automatic telephone and modern automobile is turned to the creation of machinery for our economic system, then we can evaluate the merits of classical economics. When daily wage rates are automatically calculated and simultaneously broadcast, when prices are determined by a mechanical robot affected by every change in supply and demand, only then may it be said that the economics of Adam Smith has been tested in the machine age and found wanting.

WELDING IN PRODUCTION AT FORD MOTOR CO.

(See page 672 for program of A.S.M.E. Welding Practice Symposium, Cleveland, Ohio, Oct. 22–23)

HEAT TRANSFER *in* EVAPORATION *and* CONDENSATION[1]—I

By MAX JAKOB

THE present paper, published in two parts, comprises six lectures which the author was invited to deliver at certain universities and to groups of engineers in the United States in April, 1936. The lectures are based chiefly on the contents of several papers published during the last decade by the author and some of his former coworkers; but since these papers are in German they are not easily accessible to American students and engineers. Although the present lectures do not claim to be a complete or even a systematic presentation of the subjects treated, many engineers have requested that they be published as a simple introduction to the problems of heat transfer to which they relate.

Lectures 1 to 3 are devoted to evaporation and lectures 4 to 6 to condensation. Since latent heat is the energy which is to be transferred in evaporation or condensation, the first lecture is designed to deal with experiments on the latent heat of high-pressure steam in which the author took part, and with their final results. In the second lecture the simpler and more qualitative features of the process of evaporation are considered. In the third are given the less simple quantitative results. The three lectures which are devoted to the problem of condensation begin with one (fourth lecture) on the theory of film condensation which has been improved to some extent by the author and his former coworkers. The fifth lecture contains the experimental proof of this theory, and the sixth the deviations from the theory and some recent ideas about dropwise condensation.

In the present paper the original lectures have been supplemented by some illustrations, taken from an article[2] recently published by the author's former coworker, W. Fritz, and W. Ende.

First Lecture

I—INTRODUCTION TO LECTURES ON EVAPORATION

1 ORIGIN OF RESEARCH WORK ON EVAPORATION

The lectures on evaporation should be prefaced by a brief explanation of how I came to undertake this work and how the individual parts of it originated. Although I shall cover but a small portion of our knowledge of heat, it is my intention to stress certain features that are typical of the special field of work from the point of view of the worker and his conception of heat research. The results of other researchers will be treated only in so far as they form the foundation for, or may be compared with, our own work.

The starting point was the need of values of the latent heat of water. In 1909 F. Henning gave up his experiments on the latent heat of water at 180 C = 356 F (10 technical atm corresponding to 142 lb per sq in.), because, as he explained in his paper, at this point his apparatus broke down after two days of use and was not repaired. Seventeen years later, that is just 10 years ago, I took up the work in this field. I did so because I had stated that the steam tables used at that time in Germany showed differences in their values of latent heat up to nearly 2 per cent at 210 C (19 kg per sq cm) and nearly 5 per cent at 250 C (41 kg per sq cm). I succeeded in interesting the Verein deutscher Ingenieure in this problem, calling attention to the fact that in the technically most important region the latent heat is by far the greatest part of the enthalpy of steam. At 10 kg per sq cm and 450 C, for example, the heat of the liquid is 180 and the energy of the superheat 140 kcal per kg, whereas the latent heat is 480 kcal per kg; that is, 60 per cent of the enthalpy. Even at 100 kg per sq cm and 450 C the latent heat is still 41 per cent of the enthalpy, being nearly as much as the heat of the liquid. This situation was similar to one that I had found as a young coworker of Professor Knoblauch in Munich about 1902 concerning the specific heat c_p of superheated steam. At that time engineers generally supposed c_p to be constant and equal to 0.48 kcal per kg per deg C as measured by Regnault, overlooking the fact that according to the laws of thermodynamics it must be infinite at the critical point and therefore must increase enormously with the pressure. Now, for the second time in my life, I had an opportunity to take part in research on the properties of steam in a field where knowledge was still meager.

2 PROGRESS IN THE MEASUREMENT OF LATENT HEAT AND SPECIFIC VOLUME OF SATURATED STEAM

I began, alone at first, with calorimetric measurements of the latent heat, and later worked with W. Fritz who was my assistant at that time. Table 1, which gives for the years of publication, the temperatures and pressures that we gradually reached, shows how slowly our work proceeded.

TABLE 1 MEASUREMENTS OF THE LATENT HEAT OF WATER

(By M. Jakob and by M. Jakob and W. Fritz)

Year of publication	Temperature		Pressure	
	Deg C	Deg F	Kg per sq cm	Lb per sq in.
1928	210	410	19	270
1929	250	482	41	580
1930	310	590	101	1430
1933	340	644	149	2120
1935	365	689	202	2870

Our slowness will not surprise engineers in the United States, since the corresponding work of the U. S. Bureau of Standards proceeded at about the same pace, as similar difficulties had to be overcome in all laboratories dealing with steam research.

For temperatures in excess of 365 C the calorimetric method is no longer suitable as will be seen. Therefore, some years

[1] First three of six lectures delivered to the Metropolitan and Philadelphia Sections of The American Society of Mechanical Engineers; Armour Institute of Technology, Chicago, Ill.; Polytechnic Institute of Brooklyn, Brooklyn, N. Y.; University of California, Berkeley, Calif.; Columbia University, New York, N. Y.; Cooper Union, New York, N. Y.; The Franklin Institute, Philadelphia, Pa.; General Electric Company, Schenectady, N. Y.; Harvard University, Cambridge, Mass.; University of Illinois, Urbana, Ill.; Massachusetts Institute of Technology, Cambridge, Mass.; Pratt Institute, Brooklyn, N. Y.; Princeton University, Princeton, N. J.; Stevens Institute of Technology, Hoboken, N. J., and Westinghouse Electric and Manufacturing Company, Philadelphia, Pa. The lectures on condensation will be published in a later issue.

[2] W. Fritz and W. Ende, *Physikalische Zeitschrift*, vol. 37, 1936, p. 391.

ago I began experiments in improving the direct method that Professor Callendar had used for the determination of the specific volume of water and steam in the critical region. It is known that, according to the Clapeyron-Clausius equation, the difference of the specific volumes of a saturated vapor and of the liquid associated with it depends on the latent heat. In our calorimetric measurements of the latent heat we had always used this fact to calculate the specific volume from our measurements of the latent heat. In the critical region, on the other hand, calculation of the latent heat from thermometric and volumetric measurements is to be recommended.

3 THE SUPERHEATING OF WATER AND THE PROCESS OF EVAPORATION

In his 1909 paper, Henning stated that "a lower temperature was always to be observed in the steam than in boiling water." Since the beginning of my experiments I had always been troubled by this odd difference. By observing the same difference even in my first measurements of the latent heat, I noted in my first paper[3] that errors of observation might be possible; but later the accuracy of these observations was established without a doubt. The small difference of temperatures was the more attractive to me because the patron of my first scientific work many years ago had been C. v. Linde, the famous researcher in the physics of refrigeration and inventor of the technique relative to this branch of physics. Since that time the example of the Joule-Thomson effect had been in my mind. It is well known what Linde had made of this small drop of temperature, resulting in isentropic expansion of air. Until Linde's work, this insignificant cooling was a mere physical curiosity; but Linde had used it for liquefying air, and he had further developed from this effect the entire technique of the separation of gases by means of cooling, thus creating a great branch of industry.

Having noted this, I had early learned not to overlook physical effects even though they might appear to be trifles. Therefore the research on the small temperature difference between water and steam will crop up during this and the following lectures, and even the degree of accuracy we are claiming for our measurements of the latent heat and the manner of dealing with the process of evaporation as a problem of heat transfer will be based on the insignificant differences of temperature measured in our boiler vessels.

Bošnjaković seems to have been the first to perceive the manner in which the slight superheating of water is connected with the process of evaporation. The superheating of boiling water once having been proved by our experiments, Bošnjaković, using this fact, developed in 1930 a theory about the growth of steam bubbles,[4] which we shall have to consider. Proceeding in our experimental work we studied the formation and motion of steam bubbles by photographic, stroboscopic, and cinematographic devices in order to prove and improve the theory of Bošnjaković. At the same time we carried on experiments on the relations between heating surfaces and several fluids, varying the conditions of experiment in several ways. Combining the results obtained with those relating to bubbles, we found two different laws, one dependent on the free convection of fluid, the other on the turbulent effect produced by the bubbles.

4 SUBJECT OF THE LECTURES ON EVAPORATION

In accordance with this gradual development of our work the first three lectures will deal with the following three subjects:

1 Research on latent heat and specific volume of saturated steam, especially at high pressures, based on calorimetric, thermometric, and volumetric measurements.

2 Heat transfer between fluid and vapor bubbles, based on photographic, stroboscopic, and cinematographic measurements.

3 Heat transfer between heating surfaces and fluids, based on calorimetric and thermometric measurements and on studies of vapor bubbles.

II—EXPERIMENTS ON LATENT HEAT AND SPECIFIC VOLUME OF SATURATED STEAM

1 THE CALORIMETRIC METHOD

In principle our method[5] is the same as that used by Osborne and his coworkers at the U. S. Bureau of Standards.

Referring to Fig. 1, pure water is evaporated in a closed vessel *a* by an electrical heater *b*, and the steam, carried away

[3] M. Jakob, *Forschungsarbeiten auf dem Gebiete des Ingenieurwesens*, no. 310 (1928), p. 9.

[4] F. Bosnjakovic, *Technische Mechanik und Thermodynamik*, vol. 1, 1930, p. 358.

[5] M. Jakob and W. Fritz, Festschrift zum 70. Geburtstag von Prof. Dr. A. Stodola, Zürich, 1929, p. 289.

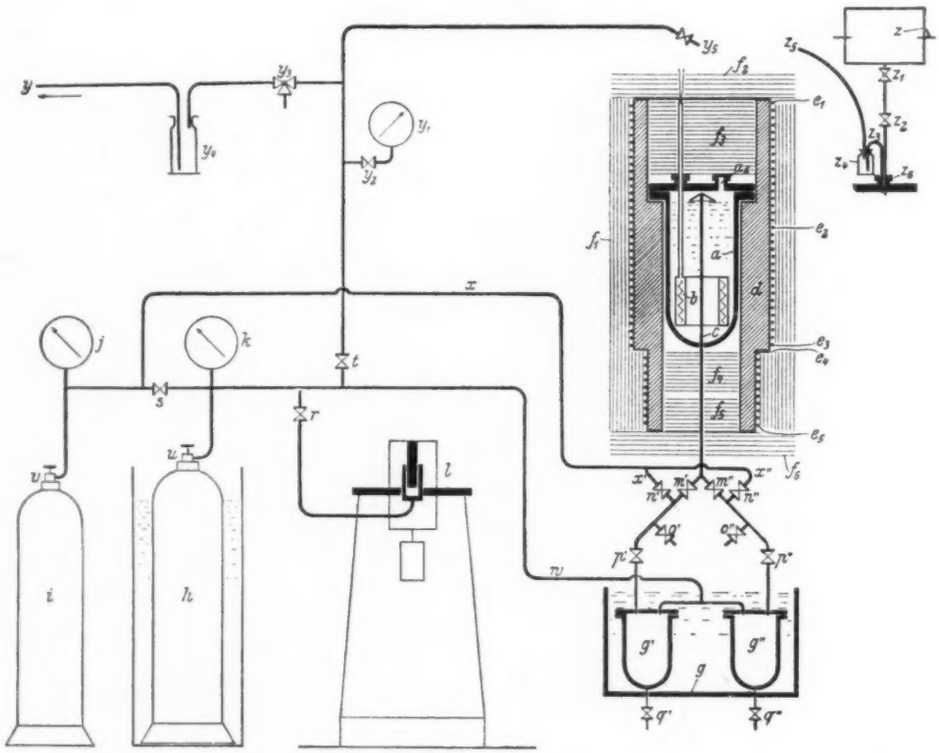

FIG. 1 DIAGRAMMATIC SKETCH OF CALORIMETRIC APPARATUS

through the tube c, is condensed at the same pressure in one of the condensers g' and g''.

A test is begun by heating the water, which almost fills the boiler, to the required boiling temperature. Then, with the electrical heating energy kept constant, the water is evaporated steadily, and the steam is condensed in the vessel g' on the left. If a steady state is reached, the flow between a and g', g'' is turned by means of the valves from the left to the right, and for a certain space of time the steam is condensed in the right-hand condenser g'' until, at a fixed moment, the valves reverse the flow to the left. From observations of the voltage and current, made by means of a potentiometer, the heating energy is determined. Also, by weighing the condensate, the quantity of water evaporated is found; and ultimately the time of evaporation and the temperature are determined. From these values the latent heat could be calculated directly, if no heat losses existed. To limit these losses, the boiler is enveloped by a protective body d, heated electrically to the same temperature as the boiler. The small remaining heat loss is eliminated by variation of the rate of evaporation, i.e., by working in subsequent tests with different amounts of heat energy, thereby condensing different quantities of steam in the same space of time. Finally, it should be mentioned, evaporation and condensation take place under the same pressure. For this purpose the cold condenser vessels are connected to a vessel containing compressed nitrogen.

Each experiment leads to a heat balance

$$N' = mr + a(\vartheta_w - \vartheta_0) + V_c \quad \ldots\ldots [1]$$

in which

N' = the heat energy N supplied per unit of time by the electrical heater, diminished by some very small corrections
m = the mass of steam formed in a unit of time
r = the latent heat
a = an empirical constant
ϑ_w = the temperature of the water in the vessel
ϑ_0 = the temperature of the envelope of the boiler vessel
$a(\vartheta_w - \vartheta_0)$ = the small heat transmission from the boiler vessel to its envelope, to be determined by separate experiments
V_c = the remaining constant heat loss of the vessel.

We did not measure the mass m of the evaporated steam, but the mass m_k of the condensate, these not being quite equal because a portion of the evaporated steam remains in the vessel, the water level therein sinking by a corresponding amount.

It will be seen at once that

$$m_k = m - \frac{v'}{v''} m = \frac{v'' - v'}{v''} m \quad \ldots\ldots [2]$$

in which

v' = the specific volume of saturated water
v'' = the specific volume of saturated steam.

This equation signifies that a part of the space, originally filled with the mass m of water, contains later on a mass of steam, smaller than m by an amount proportional to m and to the relation of the former specific volume to the later one.

Now, introducing by definition a subsidiary quantity

$$r_k = \frac{v''}{v'' - v'} r \quad \ldots\ldots [3]$$

by multiplying [2] and [3] we obtain $mr = m_k r_k$ . . . . . [4]

and by substituting this in [1]

$$N' = m_k r_k + a(\vartheta_w - \vartheta_0) + V_c \quad \ldots\ldots [5]$$

In this equation r_k is the only unknown quantity, as all the others can be determined by the experiments. Now the Clapeyron-Clausius formula is as follows:

$$\frac{r}{v'' - v'} = AT\, dp/dT \quad \ldots\ldots [6]$$

in which

A = the mechanical equivalent of heat
T = the absolute temperature
p = the pressure.

Substituting [6] in [3] we obtain

$$v'' = \frac{1}{AT\, dp/dT} r_k \quad \ldots\ldots [7]$$

and finally, substitution of this in [3] gives

$$r = r_k - ATv'\, dp/dT \quad \ldots\ldots [8]$$

From [7] and [8] the specific volume of the saturated steam v'' and the latent heat r are obtained (since dp/dT and v' are well known).

We took v' from the measurements of Keyes and Smith of the Massachusetts Institute of Technology and dp/dT from a table of Osborne and Myers. Osborne and his coworkers in the U. S. Bureau of Standards determined these quantities with their calorimeter, which is used as a universal instrument and yields all quantities for water and steam in the saturated state.

2 ARRANGEMENTS FOR CALORIMETRIC MEASUREMENTS AT HIGH PRESSURES

The principal parts of the apparatus used by us in experiments up to 100 atmospheres are shown in Fig. 2. Vessel a is made of a specially tough chromium-nickel steel, the tensile strength of which is 115 kg per sq mm at 20 C. The vessel a and its cover a_1 are held together by means of 12 strong bolts of chromium-nickel steel, a bronze sealing ring serving to make the joint tight. The inner diameter is 160 mm and the volume of the vessel is nearly 8 liters. It is not easy to make such a large vessel perfectly tight at pressures up to 202 kg per sq cm (2870 lb per sq in.) and temperatures amounting to 365 C (680 F). The inner surface of the vessel is chromium plated. The water is evaporated by the electrical heater b, which consists of a nichrome ribbon, insulated by mica, and surrounded by a silver-soldered copper shell capable of withstanding high pressures. The platinum resistance thermometer, by which the steam temperature is determined, is fixed immediately below the cover a_1 in a horizontal curved tube a_8 of stainless steel, and the tube a_7 for the resistance thermometer, which measures the water temperature ϑ_w, is arranged vertically. As an envelope, which has almost the same temperature as the vessel a, there is a large hollow aluminum cylinder d, provided with electrical coils e_1 to e_5 and protected against heat losses by air spaces at the top and bottom and on the outer cylindrical surface. These air spaces are separated by asbestos sheets faced with aluminum foil. By this division of the air space, the convection losses are greatly reduced, and the aluminum surfaces form an effective protection against radiation losses. The insulation at the top and bottom is formed by parts f_2 to f_6 which can be drawn out from above or below for inspection or repair of the boiler. The insulation is excellent and is checked by shifting two platinum resistance thermometers d_{12} in vertical holes drilled into the wall of d. The steam leaves the boiler by the tube c.

Returning to Fig. 1, which shows the general layout of the apparatus, not less than 8 valves, serving various purposes, will be noted between the calorimeter and the condensers.

For example, with the aid of them, drops of water remaining in the rather narrow tubes can be blown off by compressed nitrogen into the condensers. In the experiments it is of utmost importance that the valve closing the passage to the condenser not in use shall be absolutely tight. This is controlled in every test by opening the valve leading from the tube in question to the surrounding air of the room. With this valve, when opened, every trace of escaping steam can be noticed by means of soapy water. The dead-weight gage, which serves to indicate whether the pressure is constant and, the saturation curve being known, to check the temperature of the steam and the water, is shown in the center of the figure. The two steel vessels on the left, which are connected with the condensers, are filled with pure nitrogen in order to avoid corrosion in the apparatus. Before beginning a test, a stream of nitrogen is passed through the calorimeter to remove the remaining air, and only then is it filled from the top with distilled water, made air-free by boiling in a vacuum.

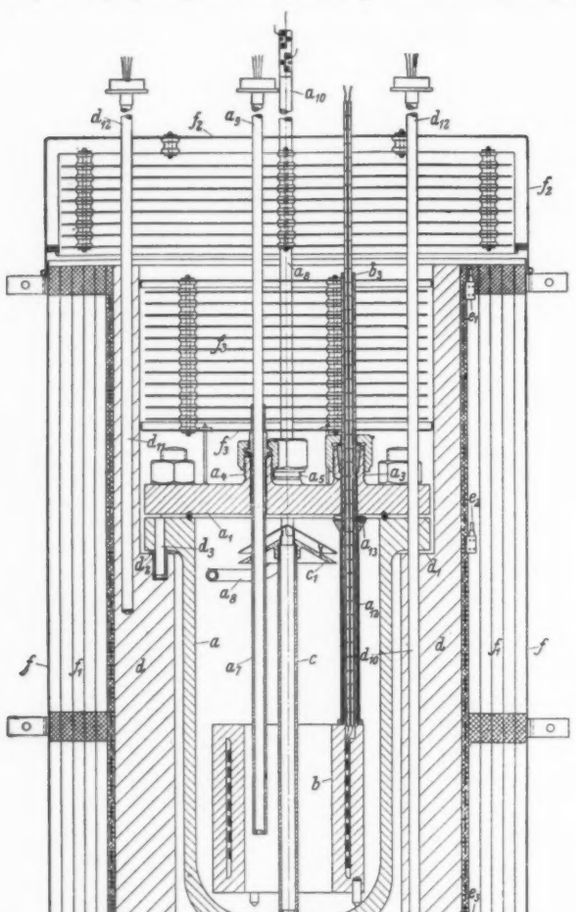

FIG. 2 VERTICAL SECTION OF APPARATUS USED FOR CALORIMETRIC MEASUREMENTS AT HIGH PRESSURES

Referring to the experiments themselves, when the calorimeter is filled with water, a series of experiments, carried out in a day at the pressures used in experiments up to 100 atmospheres, generally included four single tests with steam quantities of about 0.1 to 1.1 kg per hr, corresponding to heat energies of about 40 to 440 kcal per hr.

At the high pressures, however, the time necessary to attain thermodynamic equilibrium increased more and more, so that it was no longer possible to make three or four tests in one day. At 365 C, for example, with the pressure and the heating energy at the values that existed before beginning the definitive measurements, the increase of temperature by the last tenth of a degree C took at least 30 min. In order to be safe, we extended the time interval between two tests to 60 min.

3 EXPERIMENTS ON SUPERHEATING WATER IN THE CALORIMETER

Coming now to the differences between the temperatures of the water and the steam, there is a point where our method differs somewhat from the method used at the U. S. Bureau of Standards. Osborne restricts himself to measuring the difference between a reference block outside of the boiler vessel and different points of the outer surface of the latter. Thermocouples are placed at these points and a platinum resistance thermometer is placed in the reference block. We, on the contrary, measured the temperatures of the water and steam directly. In this way we found the very disturbing difference between the temperatures of the water and the steam. It served, however, as an incentive to make several improvements in our arrangement, to variations in the conditions of the experiment, and to a discussion of the behavior of temperatures. Moreover, this induced me, as previously mentioned, to begin my research work on the process of evaporation.[6]

Our publication[7] of 1930, reporting a series of thermometric and manometric experiments in control, showed that the steam seems to have the saturation temperature, while the water is somewhat superheated, a certain delay of boiling being noted as the reason of the phenomenon. The rate of heating energy and evaporation as well as the temperature difference between the water and the aluminum envelope of the calorimeter had no influence on the rate of superheating, this being increased only when the water level was sinking. This indicated that heat losses in the thermometer tubes might influence the result. Therefore, for experiments at pressures above 100 atm, the apparatus was altered. Fig. 3 shows our final ar-

[6] Since delivering these lectures I have had an opportunity to discuss this subject personally with Dr. Osborne. He told me that in his experiments the water probably did not boil, but evaporated without boiling, the temperatures of the water and the steam being, therefore, the same. Nevertheless, the direct measurement of both temperatures, if possible, seems to me to be preferable, since A. Heidrich has observed almost the same superheating of water evaporating without boiling as we found in boiling water (cf. M. Jakob, *Chemische Apparatur*, vol. 19, 1932, p. 109).

[7] M. Jakob and W. Fritz, *Technische Mechanik und Thermodynamik*, vol. 1 (1930), p. 173.

rangement,[8] the position of the resistance thermometer W_1 being changed unessentially, but a new movable platinum resistance thermometer W_3 being arranged on the axis of the apparatus so that the temperature of the leaving steam could be measured along the central tube. The horizontal thermometer W_2 used in the former experiments is replaced by W_3. Furthermore, although the electrical heater previously used was quite satisfactory, we changed it for a new heater, since I had designed the former one for 100 atm only. The new electrical heater consists of a bifilar coiled nickel tube, containing a single nichrome wire, around which pure asbestos fibers were wound. This heater has been used for three years up to our highest point 365 C (202 atm) without any trouble.

Measuring the temperature inside and outside the central tube, shifting the thermometers W_1 and W_3, checking them further by pressure measurements on a pressure gage, and

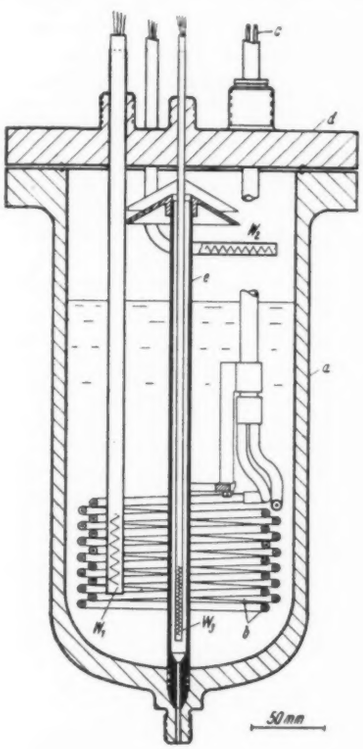

FIG. 3 FINAL ARRANGEMENT OF CALORIMETRIC VESSEL WITH TEMPERATURE-MEASURING DEVICES

comparing the results with the table of the saturation pressures of Osborne and Myers, we found:

1 That the temperature of the steam was equal to the temperature of saturation (with an accuracy of some hundredths of a degree centigrade).

2 That the temperature of the water was practically constant over the height, and by one or some tenths of a degree centigrade higher than that of the steam.

3 That in the exit tube the temperature above the water level was the same inside as outside; that below the water level the temperature of the steam decreased until it reached the temperature of water and then remained constant.

These observations based on a coiled tube as a heating surface, combined with the former ones on a vertical wall and further measurements on a horizontal plate as a heating surface, led to the values of $\vartheta_w - \vartheta_s$ represented in Table 2.

TABLE 2 DIFFERENCE OF WATER TEMPERATURE AND STEAM TEMPERATURE AS RELATED TO PRESSURE

Pressure, kg per sq cm	$\vartheta_w - \vartheta_s$, deg C
1	0.6
25	0.4
50	0.2
75	0.1
100	0.05
200	0.0

The value 0 C, which is to be expected at the critical point (225 kg per sq cm), since at this point the difference between water and steam temperature is vanishing, is practically reached at 100 atm. No influence of the form and position of the heating surface could be discovered. Further consideration of this point will be given in the third lecture.

The difference between the temperatures of water and steam causes a small correction of the latent heat because of the slight superheating of the steam leaving the calorimeter. This, of course, had been considered in the calculations previously mentioned.

4 RESULTS OF THE EXPERIMENTS ON LATENT HEAT OF STEAM UP TO 200 ATM

It is now proper to present a summary of the results we obtained by our principal experiments. We did not evaluate a day's series of tests, but always (using the method of least squares) combined all tests belonging to the same temperature, as far as they were made successively without changes in the apparatus, e.g., by adjustments to make it tight again. So our 88 series of experiments, with about 300 single tests, this number being distributed over nearly a decade, were collected into about 20 groups of tests, each group yielding one value of latent heat and specific volume.

As a most suitable form of an empirical equation, representing our results, we found

$$r = B\,(\vartheta_c - \vartheta)^n \qquad [9]$$

where

ϑ = the temperature, C
ϑ_c = 374.2 C, the critical temperature
B = a function of ϑ
n = a constant

This form complies with the thermodynamical boundary conditions

$$\left.\begin{matrix} r = 0 \\ dr/d\vartheta = -\infty \end{matrix}\right\} \text{ for } \vartheta = \vartheta_c \qquad [9a]$$

and

After many fruitless attempts we obtained as a satisfying solution

$$r = \left[a + b\left(\frac{\vartheta}{100}\right) + c\left(\frac{\vartheta}{100}\right)^2 + d\left(\frac{\vartheta}{100}\right)^5\right](\vartheta_c - \vartheta)^{0.4} \qquad [10]$$

where $a = 55.746$; $b = 1.038$; $c = 0.2532$; $d = -4.83 \times 10^{-3}$. Another equation, even somewhat better, is

$$r = \left[a + b\left(\frac{\vartheta}{100}\right)^{1.15} + c\left(\frac{\vartheta}{100}\right)^{6.5} + d\left(\frac{\vartheta}{100}\right)^{30}\right](\vartheta_c - \vartheta)^{0.635} \qquad [11]$$

where $a = 68.596$; $b = 0.8162$; $c = -1.375 \times 10^{-3}$; and $d = -0.02 \times 10^{-15}$.

[8] M. Jakob and W. Fritz, *Physikalische Zeitschrift*, vol. 36, 1935, no. 20, p. 651.

Fig. 4 shows the deviation of the mean observed values from the values calculated according to Equation [11], these being represented by the heavy horizontal line. The maximum deviations amount to from 0.15 per cent up to 240 C, to 0.25 per cent up to 340 C, and to 0.6 per cent up to 365 C (this corresponding to 202 kg per sq cm or 2870 lb per sq in.). Fig. 5 shows the differences between the values of Equation [11] represented by the axis of abscissas, and the U. S. Bureau of Standards values, published by Osborne and his coworkers. These differences amount to at a maximum from 0.25 per cent up to

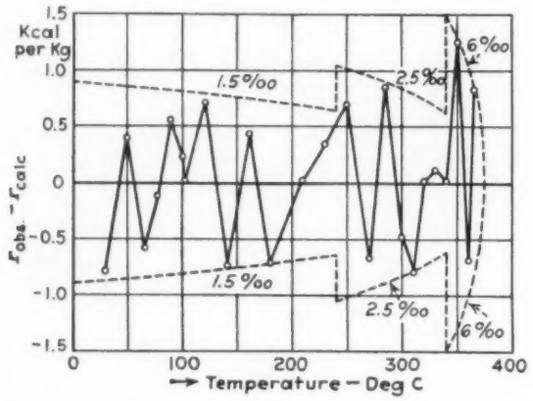

FIG. 4 DEVIATION OF MEAN OBSERVED VALUES FROM CALCULATED VALUES

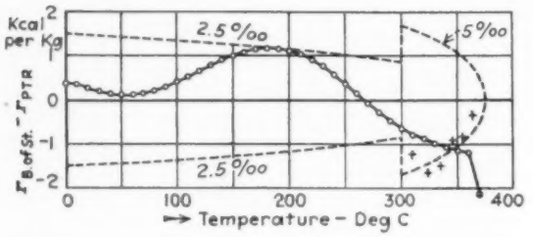

FIG. 5 DIFFERENCES OF U. S. BUREAU OF STANDARDS AND PHYSIKALISCH-TECHNISCHEN REICHANSTALT VALUES OF I

(Circles denote values of U. S. Bureau of Standards; crosses, points by Koch. In Figs. 4 and 5 ‰ signifies per thousandth part.)

310 C, to 0.5 per cent up to 350 C and to 1.5 per cent at 365 C. In my opinion this last value of Osborne is not yet definitive. Some points in Fig. 5 also represent Koch's measurements with a calorimeter for flowing steam, which differ only by 0.5 per cent from ours up to 370 C.

5 EXPERIMENTS IN THE CRITICAL REGION

Finally, there should be included here some comments on the measurements I began in order to check the measurements of Callendar in the critical region. Callendar heated small, closed, quartz tubes containing different masses of water until either the water expanded to fill the entire tube or until all of it was evaporated. In the first case the volume of the tube and the weight of its contents gave the specific volume of saturated water, in the latter that of steam. I used an apparatus consisting of a hollow cylinder of silver with two slits through which the meniscus could be seen with a telescope. The difference from Callendar's arrangement consists in the method of determining the temperature. I suggested the use of a platinum resistance thermometer inserted in a quartz tube, similar to the quartz tube containing the water, to compare the temperature shown by this thermometer with that of Pt-Pt-Rh thermocouples inserted into the wall of the silver cylinder. The experiment is thus divided into two parts, the first consisting in gaging the thermocouples on the resistance thermometer, the second in determining with the thermocouples the temperature of vanishing meniscus. In order to make the two arrangements entirely similar, a piece of quartz was arranged to lengthen the quartz tube upward, and to conduct upward the same amount of heat as was being conducted by the stem of the quartz thermometer in the gaging experiment. By this arrangement the advantages of resistance thermometry and thermometry with thermocouples are combined. Applying auxiliary heating coils at the ends of the cylinder, Mr. Eck, my former assistant who now carries on with the experiments, has succeeded in getting a temperature difference of only ±0.015 C over the entire length of the tube. The temperature increase in the apparatus can be adjusted to 0.1 C per hr. The volume of the tube is determined after opening it by means of grinding its closed end. The tube is then filled with mercury and is weighed in both full and empty condition. Some results, obtained on this apparatus, were presented to the Third International Steam Tables Conference held in United States in 1934.

Mr. Eck has been trying to find out whether a solution of quartz in the water affects the results. I do not think that it does. In any case he has not obtained the same strange results found by H. L. Callendar, who observed a latent heat of 72.4 kcal per kg even at the critical temperature of 374 C and a latent heat of zero only at 380.5 C. In this connection I should like to quote a sentence from a report delivered in 1929 to the World Engineering Congress, Tokio, by H. N. Davis and J. H. Keenan: "The apparent existence of a true latent heat in accordance with Callendar's suggestion, and the existence of very large specific heats in this region as required by the classical critical-point theory, would be, from the experimental point of view, two pictures so nearly identical in every observable respect as to be indistinguishable."

I hope that the measurements of my former coworker will definitely clear up this point.

Second Lecture

III—EVAPORATION AS A PROBLEM OF HEAT TRANSFER

1 GENERAL NOTIONS AND THEORETICAL POINTS OF VIEW

The first lecture dealt with the typical calorimetric problem of determining a property of steam, i.e., the latent heat, this being connected thermodynamically with a second property, the specific volume of saturated steam, and to some extent also with other properties (change of pressure with the temperature of saturated steam and the specific volume of saturated water). This property, as a function of the pressure up to 200 atm, had to be determined in a research laboratory, fitted with apparatus for measurements of high precision. The experiments extended over nearly a decade and funds of considerable size, granted by technical and scientific bodies, had to be expended. All this work formed but a link of a series of experiments, performed in the United States and in Europe in order to obtain the properties of steam as exactly as possible and to incorporate them in steam tables for practical use. To this end an international agreement has been reached by three steam-tables conferences, held in England, Germany, and the United States. By this means the knowledge of the thermodynamical properties of steam has reached a high stage of perfection, if we except the region of the highest pressures and some particular points.

In contrast to this, knowledge of the processes connected

with the generation and condensation of steam has been developed but little. In lectures I delivered at the University of London five years ago, I called these processes "dynamical," embracing under this term, in a wider sense, hydrodynamical motion, heat transfer, and changes of state. Unfortunately, it is not possible to separate these three groups of phenomena. The process of evaporation, for example, that will be dealt with in this and the third lecture, is a change of state in which heat transfer and hydrodynamic convection play decisive parts.

When I began to study the question of evaporation I was amazed at our general ignorance concerning it. Mankind probably became acquainted with the process of evaporation immediately after the invention of the first earthenware jars, not a long time after having gained possession of fire. Hence, because they were familiar with evaporation, men have apparently considered this process as so natural and self-evident that neither women, looking into their teakettles, nor engineers, standing before their opaque boilers, have considered it necessary to inquire more thoroughly into what was actually going on. Therefore it was not until recent years that we became aware that we knew practically nothing about this problem. Although the physical conditions necessary for the existence of steam bubbles have been known for a long time, physicists have shown much greater interest in the processes in the interior of a steam molecule than in what happens at the outside of a steam bubble, and engineers have succeeded in designing boilers for high pressures and loads without being able to calculate exactly the temperatures of the tubes of these boilers. For a long time it was not absolutely necessary to know these temperatures; but at present, engineers, working quite near the limit of the tensile strength that is extraordinarily influenced by temperature, must know them. I should like to mention this point only, although a thorough knowledge of evaporation is likewise necessary to many other purposes.

Before beginning an analysis of the process of evaporation a few general remarks are in order. When the liquid and gaseous phases of a substance exist together, one of the conditions of equilibrium is that of masses; that is, the same number of molecules must always pass in both directions through an area separating the two phases. Therefore, the process of evaporation—that is, the continual one-way migration of molecules into the space of the steam phase—is not strictly in accordance with the conditions of thermodynamic equilibrium.

It may be asked how a steam bubble originates in the liquid. If steam is able to exist as a separate phase, a surface of separation is necessary, as, for instance, in a sphere; but the liquid offers resistance to the formation of such a curved surface, and the question of surface tension has to be considered. This tension in the interior of a small bubble surrounded by the liquid causes a lower steam pressure than would be found at the same temperature on a plane surface. The laws applicable to this case have been set forth by W. Thomson (Lord Kelvin). According to these laws a concave fluid surface is not at the saturation pressure p_s, but has the lower steam pressure

$$p_c = p_s - \frac{2\sigma}{R}\frac{\rho''}{\rho' - \rho''} \quad \ldots\ldots\ldots\ldots\ldots [12]$$

where

p_c = saturation pressure at a concave fluid surface
p_s = saturation pressure at a plane fluid surface
R = radius of the concave surface
σ = surface tension
ρ' = density of saturated fluid
ρ'' = density of saturated steam.

Because of this, the fluid must be superheated near the steam bubble, the superheat increasing with the decreasing radius of the bubble.

From this follows the strange result that in an absolutely pure liquid no vapor bubbles can originate at all, the initial diameter of such bubbles being infinitely small and the superheat infinitely high. Indeed, pure water at atmospheric pressure could be highly superheated without ebullition. Actually, however, water can be evaporated without considerable superheating if care is taken that there exist in the liquid sufficiently small curved surfaces on which the steam molecules can collect. Such curvatures, for instance, exist in the rough surfaces of the walls, and in the little bubbles of gas adhering to the walls, in which the liquid can evaporate. According to this idea, a rapidly boiling liquid could not be greatly superheated, since the bubbles arising on the curved surfaces would disturb the state of surface tension, especially since, owing to the convection of the rising bubbles, the temperatures become equalized. On the other hand, the heat transmission from the heater to the places where the bubbles originate causes differences of temperature in the liquid.

From these considerations the slight superheating observed in our high-pressure calorimeter for steam, as mentioned in the first lecture, could be understood qualitatively.

As brought out in the first lecture, it was Bošnjaković who recognized that this slight superheating provides the impulse to heat transmission needed for evaporation. Because of the difference in the temperatures of fluid and vapor, heat is flowing from the fluid to the surfaces of the vapor bubbles, and on these surfaces the fluid is evaporating into the interior of the bubbles.

Bošnjaković further uses the fact that the heat energy dQ conveyed to a growing vapor bubble is given by the product of the latent heat r and the increase dM of the mass of the bubble. So he comes to the heat-balance Equation [13] and from this, with certain simplifying assumptions, derives Equation [14] of the superheating of the vapor.

$$dQ = r dM = \alpha_B S \Theta_w \, dt \quad \ldots\ldots\ldots\ldots\ldots [13]$$

$$\Theta_w = \frac{H_B}{\alpha_B} = \frac{1}{\alpha_B}\frac{r}{v''}\frac{dR}{dt} = \frac{1}{\alpha_B}\frac{r}{v''} w_B \frac{dR}{dh} \quad \ldots\ldots\ldots [14]$$

In these equations

r = the latent heat of saturated vapor
v'' = the specific volume of saturated vapor
R = the mean radius of curvature of the surface of the bubble
S = the surface area of the bubble
h = the height of the bubble above the heating surface
w_B = dh/dt the vertical component of the velocity of the bubble
dQ = the heat transmission to the bubble in the time dt
dM = the mass transmission to the bubble in the time dt
Θ_w = $\vartheta_w - \vartheta_s$ the difference of temperatures of fluid and bubble
H_B = the density of heat flow from fluid to bubble.

From this Bošnjaković calculated that for a steam bubble rising with the velocity $w = 16$ cm per sec to a height of 100 mm and increasing to the diameter of 12 mm, the coefficient of heat transfer α_B would be 36,500 kcal per sq m per hr per deg C and the surface layer in which the temperature drop is concentrated would be 0.017 mm. We shall see that this value of α_B in general is at least twice too large.

Bošnjaković treated only the heat transfer between the water and the bubble; but an immediate consequence of his theory is the assumption that the direct heat transmission from the heating surface to the bubble may be neglected, and that

the heat transmission from the heater to the bubble is divided into two parts: First, the heat transfer from the heating surface to the boiling fluid, and second, the heat transfer from the fluid to the bubble. Although I shall endeavor to treat these two problems separately, their intimate connection will compel me to pass several times from the one subject to the other.

2 ARRANGEMENT OF APPARATUS FOR THERMOMETRIC AND CALORIMETRIC MEASUREMENTS

In contrast to the experiments of the first lecture, in which measurements were made with an apparatus designed for high pressure, all of the following experiments were made at atmospheric pressure. We must first describe the apparatus used to determine the temperature distribution in boiling liquids

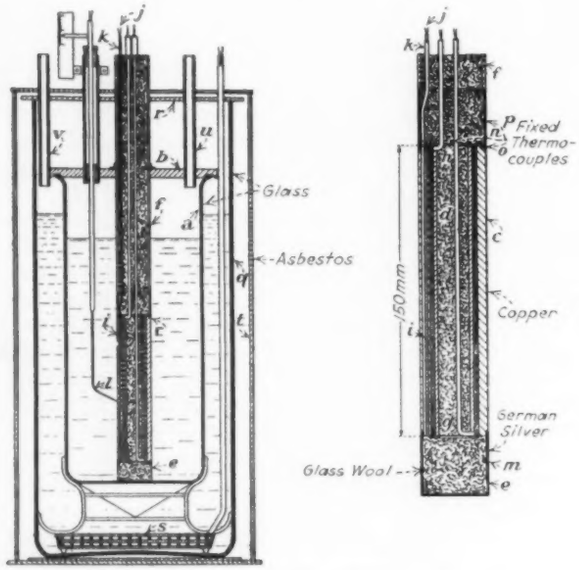

FIG. 6 VERTICAL HEATING SURFACE USED IN TESTS

near the heating surface and the relation of the heat flow (related to the unit heating area) to the drop of temperature between the heating surface and the fluid.

Fig. 6 shows at the left the general arrangement for a vertical heating surface.[9] The cylindrical heater stands in a glass vessel *a*, which contains the fluid to be evaporated. The ground edge of the vessel has a brass cover *b*, which is sufficiently tight.

The heater is shown to a larger scale at the right of Fig. 6. The outer hollow cylinder *c* of copper is 150 mm long. The outer diameter is 35 mm; and the thickness of the wall is 5 mm in order to make possible the drilling of axial holes throughout its entire length for thermocouple *j* (and a second one not shown) to be shifted therein. Since it was impossible to drill axial holes 150 mm long and 1.5 mm in diameter, we drilled holes 3 mm in diameter and bushed them either with a copper tube of 1.5 mm inner diameter or with a copper wire fitted with a groove. Fine tubes *k*, containing the thermocouples, were threaded through the copper tube or the groove in the copper wire. The nichrome heating wire, covered with pure asbestos fibers, is wound on an inner brass tube *d*. The outer tube *c* is lengthened downward and upward by tubes *e* and *f* made of German silver, 0.5 mm thick, these serving as hydraulic starting and terminal surfaces for the convection flow of the liquid. These terminal pieces were coppered, chromium-plated, and polished, as was also the copper tube forming the heating surface. Because of the tenfold smaller thickness of the terminal pieces and the nearly fifteenfold smaller heat conductivity of the material, compared with copper, the axial heat loss is reduced to an entirely negligible amount, the more so as the temperature of the heating surface is not much higher than that of the boiling fluid. Moreover, in our last experiments the tube, lengthening the heater surface upward, is shortened so that only some thin nickel tubes, containing the terminal leads of the heating coil and the thermocouples, are led outside through corks fitted in the cover. The entire space inside the heating body and the heating coil is filled with glass wool.

The thermocouples used consisted of iron and constantan wires, each 0.2 or 0.25 mm in diameter. Besides the two thermocouples in the tube there is to be seen a third thermocouple *l* that can be shifted and turned in the fluid, and, at the right, four thermocouples for checking the temperature of the terminal pieces.

The evaporating chamber is arranged in a second glass vessel, which contains the same fluid as the inner one, and is closed in a similar manner by a cover. By an electrical heater arranged above the bottom of the outer vessel the fluid in the outer vessel is also evaporated, the levels being held at nearly the same height in order to have the same conditions inside and outside and to avoid any heat losses from the inner vessel. The outer vessel is insulated by asbestos sheets, arranged with two opposite slits so that the interior may be lighted and observed.

The two open tubes *u* and *v* passing through the lids lead to water coolers, three being arranged, one after the other. For safety in our measurements with carbon tetrachloride, its vapor being disagreeable to the mucous membranes, we put the entire apparatus under a tube 370 mm in diameter leading to a ventilator, by which vapors escaping from joints that were not tight were carried into the open air.

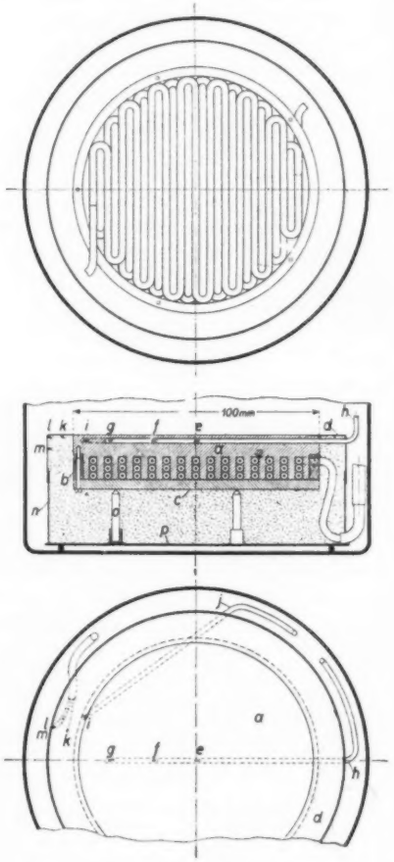

FIG. 7 HORIZONTAL HEATING SURFACE

The arrangement of the apparatus with the horizontal heating surface corresponds to that with the vertical surface.

The newest form of the heating body is shown in Fig. 7. It consists of a thick copper plate *a* with 16 ribs of copper soldered to it with silver, so that three layers of nichrome wire, covered with pure asbestos, can be placed between them. With this arrangement we got a density of heat flow, rising vertically into the fluid, up to $H =$

[9] M. Jakob and W. Linke, *Physikalische Zeitschrift*, vol. 36, 1935, p. 267.

260,000 kcal per sq m per hr, corresponding to 95,500 Btu per sq ft per hr and to an evaporation of 480 kg per sq m per hr, or 98 lb per sq ft per hr referred to water at 100 C. This load, large even for the front rows of an inclined-tube boiler, was obtained in a glass vessel, the "storm" in the water glass certainly being enormous. It was not possible to obtain such large loads with our vertical heaters, these being suitable only up to about 60,000 kcal per sq m per hr, i.e., not even the fourth part of the highest value obtained with a horizontal heater. The reasons for this difference are obvious.

On the other hand, the radial heat losses of a horizontal heater, though not considerable, are not so easily eliminated as in the case of vertical surfaces. The best design, we found, is shown in Fig. 7. In this type the edge *d* of the copper plate is of German silver, only 0.2 mm thick, chromium-plated, and polished like the copper plate. By this means the radial heat loss of the plate is greatly diminished and is susceptible of calculation. Moreover, the plate surface is enlarged hydraulically, the heating surface remaining unchanged thermally. The arrangement of the seven thermocouples *e*, *f*, *g*, *i*, *k*, *l*, and *m* and the glass-wool insulation of the whole body, soldered in the nickel vessel *n*, can be seen in Fig. 7.

The principal experiments on these and similar heater surfaces consisted in measuring the heating energy, produced electrically, by voltmeters and ammeters of precision and in measuring the temperatures of the surface and the boiling fluid by means of thermocouples and a potentiometer. The difference between the surface temperature and the fluid temperature will be denoted by Θ. The heat transfer at the end of a cylindrical vertical tube may be calculated by

$$\Theta = \Theta_0 \, e^{-x} \sqrt{\frac{u\alpha}{f\lambda}} \qquad [15]$$

known as the equation of temperature excess Θ of a bar at the distance x from one end, Θ_0 being the value of Θ at $x = 0$, u the length of the circumference, f the area of the cross section, λ the heat conductivity, and α the coefficient of heat transfer between the surface of the terminal pieces and the water, which does not boil at the terminals. The same formula is applicable to the edge of the horizontal plate.

3 APPARATUS FOR PHOTOGRAPHIC, STROBOSCOPIC, AND CINEMATOGRAPHIC MEASUREMENTS

We come now to the second case, i.e., the heat transfer between the fluid and the vapor bubble.

In order to prove the Bošnjaković theory we used photographic and cinematographic means. First, we determined the general character of steam and carbon-tetrachloride bubbles, adhering to the heating surface or rising in the fluid. The photographic work consisted in taking snapshots of bubbles above a horizontal heating surface, the evaporation being rather rapid. Exposures were timed between 1/200 and 1/25 sec. A scale, suspended in the liquid, was photographed with the bubbles in order to provide a means for finding out the size of the bubbles. Other exposures served to determine the contact angle between the heating surface and the bubbles while resting on a horizontal plate, just before leaving the base. The bubbles were produced on a horizontal copper plate, chromium plated and polished at a temperature below that of saturation. The snapshots were taken a few seconds or parts of a second before the bubbles broke off. The angles were measured by a mirror ruler and the volumes by planimetering the areas of the photographs of the bubbles. We shall return to this in the third lecture.

In addition, stroboscopic measurements were made in order to obtain information as to the frequency of formation of bubbles. For this purpose we cast the light of a powerful electric bulb on rising bubbles, using cardboard disks with two to eight slits revolving 200 to 1000 times per minute. For each of the liquids used we found a certain frequency of exposure at which most of the bubbles seemed to stand still. The interpretation of the results caused some difficulty, since the fiction of standing still took place at several frequencies. But a simple consideration shows that the true frequency of the bubbles is equal to that frequency of exposure which, doubled, makes double the number of bubbles appear, while half the number of exposures does not alter the number of bubbles.

The cinematographic pictures were taken by means of a high-speed camera developed by W. Ende in the research laboratory of the A.E.G. The experiments were conducted by my former coworker W. Fritz. The film reel, passing the objective continually, was exposed by means of four converging lenses, revolving with the film, the picture standing still against the moving film reel during the exposure. Black time marks were recorded by means of an automatic electrical device in intervals of 1/100 sec, the frequency of pictures being 500 to 600 per sec. The length of the film being 10 m, the exposure time was 1 sec, with an additional starting length of 40 m to permit the motor to reach a practically constant speed.

The steam bubbles were produced by a horizontal electrical heater similar to that previously described; but the boiler vessel was arranged inside a similar vessel of square section, so that the exposure took place through plane parallel walls, distortions being excluded. A metallic bar suspended in the evaporator chamber served as a scale. A steady state being established, the heating of the outer vessel was stopped just before the exposure in order to get rid of bubbles disturbing the pictures. The bubbles were illuminated from behind by an arc lamp, and a screen of oilpaper was placed between the lamp and the vessel, in order to obtain diffused light. Thus, the bubbles gave distinct black images on a bright background.

4 SOME QUALITATIVE RESULTS OF MEASUREMENTS

Some qualitative results of our experiments will be shown first, the more quantitative results and theoretical consequences, being reserved for the third lecture.

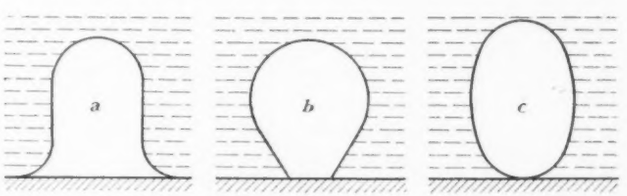

FIG. 8 TYPICAL SHAPES OF STEAM BUBBLES ON HEATING SURFACES (*a* = screen surface with thin oil layer, not wetted; *b* = chromium-plated and polished surface, half-wetted; *c* = screen surface, clean, entirely wetted.)

First, we examined the influence of the surface upon the evaporation on a horizontal heating plate. For this purpose we compared smooth surfaces (chromium-plated and polished) with those roughened by means of a sand blast, and others fitted with square cavities, the lengths, depths, and spacings of which were about 0.25 mm. This we shall call a "screen" surface. In these experiments we observed three typical shapes of steam bubbles on the heating surfaces, Fig. 8. Case *a* occurs on unwetted surfaces. Such a surface was produced by covering the screen surface with a thin layer of oil. This was suitable for observations during a limited space of time until the oil was swept away by the water and the steam. Case *b* (half

wetting) is obtained by evaporation from a smooth surface; case *c* (total wetting) is produced on the screen surface, since the roughness counteracts the effect of surface tension.

The manner of the origin, the size, and the number of these three types of steam bubbles showed characteristic differences. The bubbles of the first type spread themselves out on the unwetted surface. Apparently, the free edge of the bubble is drawn into a fine wedge between fluid and heating surface and thus is held fast against the action of buoyancy. Therefore, the bubble gets rather large (up to about 8 mm) before being detached, and is replaced at once by a new one. In this way we must imagine the evaporation of pure mercury in a mercury-vapor boiler. I suppose that in this case a part of the heating energy is transmitted immediately to the vapor contents of the bubble, this being slightly superheated. The small contact between surface and liquid will also cause but a small heat transfer, and the electrical heater is in considerable danger of being burned through.

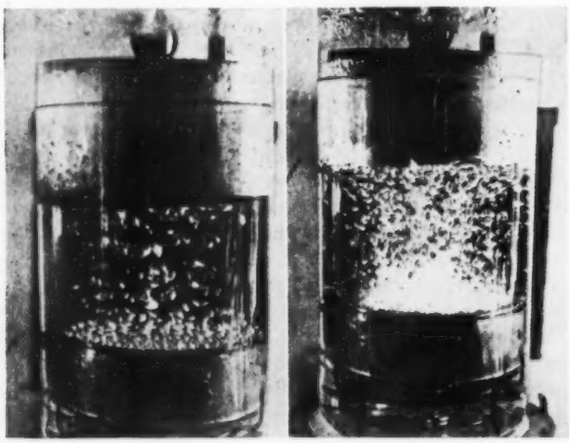

FIG. 9 FORMATION OF BUBBLES ON SURFACES OF TYPE *a* (LEFT) AND TYPE *c* (RIGHT)

The evaporation on smooth surfaces (type *b*) is entirely different from the former type. The bubbles originate at only a few small places of the plate, these not being distinguished by any peculiarities whatsoever from the rest of the surface and therefore being irregularly distributed over it. One has the impression that columns of steam are issuing from these points and that these columns become larger as they rise. Photographs show that these columns consist of a great number of steam bubbles, rising one after the other. The number of these points increases with the load; e.g., on a plate having a diameter of 100 mm, we counted only 5 such points (all of them at the edge of the disk), the heat flow being $H = 7500$ kcal per sq m per hr, 8 places (5 of them at the edge) for $H = 15{,}000$, and 24 places (again 5 at the edge) for $H = 30{,}000$. The columns are swaying, owing to the effect of convection. The points from which the bubbles originate, appear as small, dim, violet circles after the plate has been removed from the water.

In the case of bubbles of the third type, the fluid tends to push away and to shear off the bubble, which rests at only one point and becomes globular or oval and leaves the surface while still very small.

Fig. 9 shows, at the left, a number of bubbles of type *a*, and at the right others of type *c*, both being taken with about the same rate of heat flow and with the same time of exposure. At the left there are a comparatively few big bubbles, so that the fluid appears dark. At the right, on the contrary, the great number of small bubbles causes the visual field to appear bright.

Fig. 10, for which I am indebted to The Dampney Company of America, Boston, Mass., represents two phases of different kinds of evaporation, the heating being about the same.[10] The illustration shows two short pieces of $1^1/_2$-in. O.D. steel boiler tube, each containing a 300-watt electric cartridge-type heater element fitting snugly into the tubes, which are closed by brass disks at the bottom. The tube on the left was smoothed, and the right was uniformly painted with a graphited mass called Apexior No. 1. Each photograph is said to have been taken in 1/100,000 sec by the light of a 16,000-volt spark. On the left evaporation exists at only a few places, as previously explained, the columns of steam being clearly separated into single bubbles, one following the other, as can be distinctly seen. The right-hand photograph shows that the rough painted surface gives rise to the development of bubbles at many places, probably owing to many elements of roughness formed by the graphite and the gas adhering to it.

FIG. 10 FORMATION OF BUBBLES ON BOILER-TUBE SURFACES THAT ARE SMOOTH (LEFT) AND PAINTED WITH APEXIOR NO. 1 (RIGHT)

The picture on the left also shows the increase and change in the shape of the rising steam bubbles, if these are compared with succeeding ones in the steam column.

This can be still better recognized in an illustration from one of the high-speed camera films previously mentioned.[2]

In one of these taken with a heat flow of $H = 6800$ kcal per sq m per hr only three steam columns were formed. The bubbles were small and their frequency so great that only the rising column could be observed. They began to rise fairly straight as small globules. After a certain point they gradually took the shape of lenses, the motion becoming helical because of the tilting of the lenses. In arriving at the surface of the water the diameter was about 5 mm.

The illustrations shown in Fig. 11 were cut from another film

[10] See also *Power*, April, 1934, p. 207.

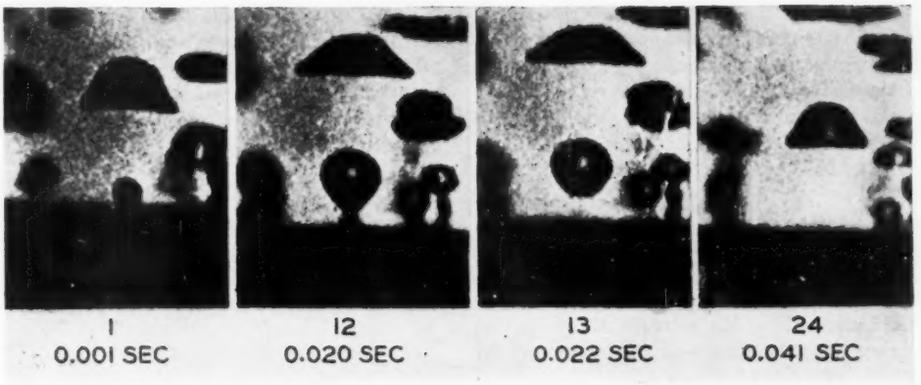

FIG. 11 SOME FRAMES SELECTED FROM A SERIES OF 24 MOVING PICTURES FRAMES SHOWING BUBBLE FORMATION

(with $H = 19{,}300$), eight steam columns being active. The objective was to obtain larger bubbles, these increasing up to a diameter of 10 mm. The illustration shows some characteristic phases of two bubbles. These are four out of 24 frames taken in 0.04 sec. In frame No. 1 a bubble is forming at the heating surface; 0.02 sec later (frame No. 12) it is about to leave the base; 0.002 second later (frame No. 13) it is free. The tail which will be noted jerks upward and indents the lower portion of the surface of the bubble, the surface tension, together with the flow of the rising bubble, forcing the bubble into the form of a tin hat (frame No. 24). In frame No. 1 the preceding bubble will also be seen, looking like a hat. In the two following frames, this hat is flattening. In the fourth frame it has passed out of the field of view.

The distribution of temperatures above the heating surface up to the steam region has also been cleared up by our experiments,[11] as can be seen by the examples, shown in Fig. 12. In every test the temperature changed suddenly at the water-level surface from the somewhat higher temperature of the water to the saturation temperature of the vapor, this being true in the entire steam space. The mean superheating of the water changes but little with the speed of evaporation, represented by the rate of evaporation H; this being 246 kcal per sq m per hr in the upper diagram and 37,000 in the next one, both referred to polished surface. Although, according to this, the rate of flow in the center diagram was 150 times that in the first diagram, the drop of temperature at the water-level surface was nearly the same. The change at the water-level surface is greater for a smooth heating surface (see the center diagram) than for a rough one (as in the lower diagram, this referring to a screen surface with $H = 39{,}200$). As average values we found a difference of 0.5 C for smooth and 0.3 C for rough heating surfaces.

In the close proximity of the heating surface the superheating of the water increases greatly up to the temperature of the surface, indicating that a thin layer apparently exists, not mixed by convection, similar or equal to the well-known Prandtl boundary layer. In contrast to the temperature drop at the water-level surface, the temperature drop in this layer (not to be completely seen in the diagrams) depends on the heat flow, this drop being 0.4 C for the upper diagram and 10.1 C for the central one; according to this the 25-fold drop belongs to the 150-fold load. Comparing the two lower diagrams, it is worth while mentioning that the drop of temperature is greater in the case of smooth surface than in the case of the screen surface, the change (related to the same load) being 10.1 C and 5.5 C, respectively, on the heating surface and 0.4 C and 0.2 C, respectively, at the water-level surface. It is obvious that the greater roughness facilitates evaporation on the heater surface, the elements of roughness having greater mean radii of curvature than occur on smooth walls. The smaller change at the surface may be explained by better convection, the load being the same, while better convection, that is caused by increased heating, seems not to have so considerable an effect.

[11] M. Jakob and W. Fritz, *Forschung auf dem Gebiete des Ingenieurwesens*, vol. 2, 1931, p. 435.

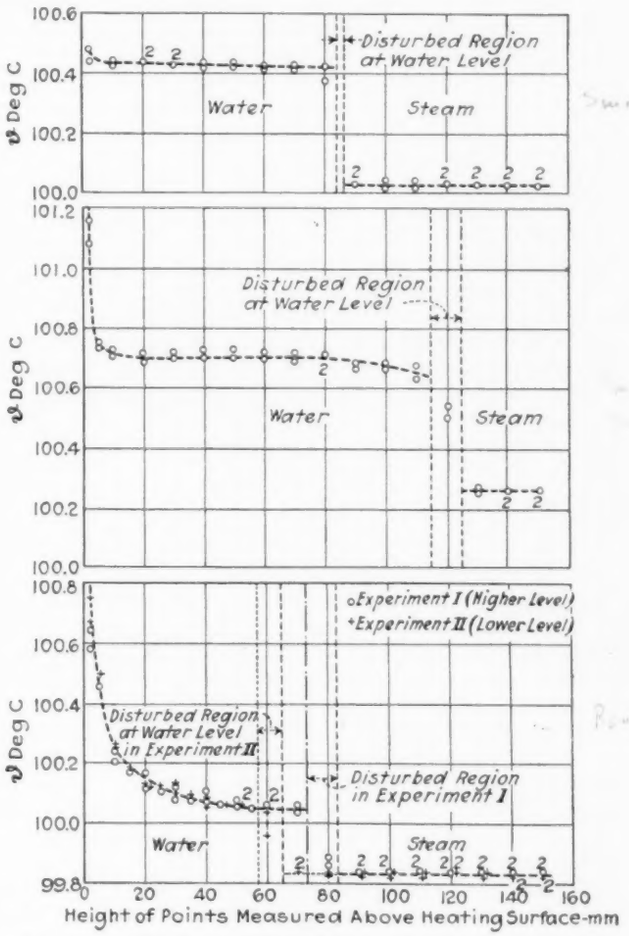

FIG. 12 TEMPERATURE DISTRIBUTION ABOVE HEATING SURFACE

The thin layer of fluid near the heater wall, which is more highly superheated than the main mass of the fluid, should be considered separately in discussing the process of evaporation.

Since the bubbles originate in this layer, they are exposed to a hotter environment at the beginning of their development.

Thus, while the mean superheating of the fluid depends but little on the rate of evaporation, this being in agreement with the theory of Bošnjaković, this does not hold good at all for the superheating of the liquid at the heating surface. Now even this superheat, in addition to the thin cells formed by roughnesses, is essential for the process of evaporation, for the following reasons:

(1) The fluid being superheated to a higher degree, vapor bubbles can originate at smaller curvatures of the surface elements (formed by roughnesses or gases entrained in the liquid and getting free). Because of this, the increase of the number of places of evaporation with the energy of the heater, which has been observed, can be explained.

(2) Since the fluid is superheated to a higher degree, more vapor bubbles will originate at any one of the places of vapor formation. Because of the greater temperature difference, more heat energy will be transmitted to the surface, which is at first extremely small, of a bubble that has originated there and is now in contact with the heating surface. Thus the bubble will increase and be torn off more quickly, so that the element of roughness in question will be more often available for the formation of a new bubble. Finally, the larger number of bubbles formed as the result of the higher superheating on the wall will also absorb more energy in rising, unless the mean superheating of the fluid might be smaller at higher load because of the cooling effect of the rising bubbles.

A further effect, consisting in the stirring of the fluid by the rising bubbles and in the increase of heat transfer at the heating surface caused by this stirring motion will be treated in connection with the more quantitative results of our experiments, which will form the material for the following lecture.

Third Lecture

5 PHOTOGRAPHIC, STROBOSCOPIC, AND CINEMATOGRAPHIC EXPERIMENTS AND THEIR EVALUATION

In order to prove the Bošnjaković theory and to recognize more distinctly the mechanism of evaporation, I set up photographic and cinematographic experiments which were reported briefly in the second lecture. In the present lecture we shall deal with the results of these measurements.

Just as the entire process of evaporation was divided into two partial processes, the heat transfer from the heating surface to the water and the heat transfer from the water to the steam bubble, so also the conditions essential for the development of a bubble are twofold, different laws holding for the bubble adhering to the heating surface and for its growth while rising. The two cases differ from each other by the relative differences of temperature as well as by the manner of the hydrodynamic motion.

The growth of the bubble at rest could be observed with sufficient exactness only in the case of rather large bubbles, and not with the smaller ones. But, fortunately, the development of the bubble at rest is theoretically well known; and, particularly, the volume at the moment the bubble breaks off has been calculated exactly. While these calculations refer only to the case of equilibrium between surface tension and buoyancy, in our case convection exerts forces as well, these assisting in shearing the bubble from the surface. We shall see later whether or not convection forces may be neglected.

Concerning this it is sufficient to say that the shape of a free surface, on which only the surface tension and gravity are acting, is determined from the theory of capillarity. Although the differential equation relating to a body of axial symmetry cannot be solved exactly, Bashforth and Adams[12] have given an approximate solution and tabulated the results to a considerable extent. Based on their work and on a paper of Wark,[13] my coworker of that time, W. Fritz,[14] has derived a dimensionless expression for the maximum volume V_{max} of bubbles having the relationship $\sqrt[3]{V_{max}}$ to the Laplace constant a as a function of the contact angle θ. The Laplace constant is defined by the equation

$$a = \sqrt{\frac{2\sigma}{g\,(\rho' - \rho'')}} \qquad [16]$$

where

σ = the surface tension
g = the acceleration of gravity
ρ' = the density of saturated water
ρ'' = the density of saturated steam

Fritz has further calculated the maximum volume of bubbles for different fluids and angles. For instance, the maximum volume of a bubble with the contact angle of 100 deg would be:

95 cu mm for an air bubble in water at 20 C
75 cu mm for a steam bubble at atmospheric pressure
25 cu mm for a steam bubble at 50 atm or a bubble of mercury vapor at atmospheric pressure
10 cu mm for a steam bubble at 100 atm or a bubble of carbon-tetrachloride vapor at atmospheric pressure

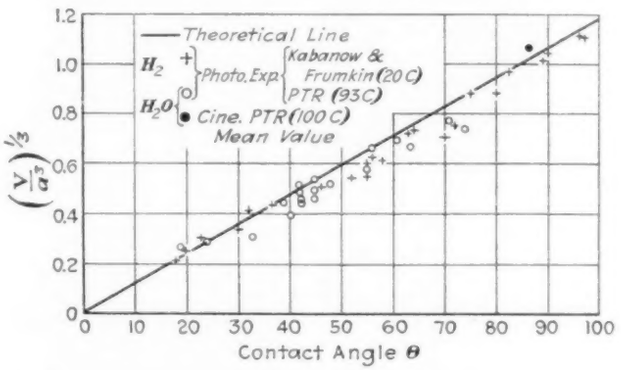

FIG. 13 RELATION BETWEEN MAXIMUM VOLUME OF BUBBLES AND CONTACT ANGLE ACCORDING TO FRITZ'S CALCULATION

Fig. 13 shows a straight line representing the relation between the maximum volume of bubbles and the contact angle according to the calculations of Fritz.[2] The small circles refer to the angle measurements on the photographs of steam bubbles, mentioned in the second lecture. These measurements were most thoroughly made by my former coworker H. Kipcke. The numerous crosses refer to hydrogen bubbles, formed in greatly diluted solutions at 20 C, according to measurements by Kabanow and Frumkin[15] (a = 3.853 mm). The deviation between the theoretical curve and the experimental points is insignificant and is partially caused by the disturbance of equilibrium in the experiments, as previously mentioned. In any event, the disturbance in vigorous ebullition will be considerably greater.

[12] Fr. Bashforth and J. Adams, "Capillary Action," Cambridge, 1883.
[13] J. W. Wark, *Journal of Physical Chemistry*, vol. 37, 1933, p. 623.
[14] W. Fritz, *Physikalische Zeitschrift*, vol. 36, 1935, p. 379.
[15] W. Kabanow and A. Frumkin, *Zeitschrift für Physikalische Chemie*, A, vol. 165, 1933, pp. 316 and 433.

Coming now to the evaluation of the cinematographic pictures, it should be stated that six steam bubbles were followed continuously from the very beginning till they reached the water-level surface. Three hundred steam bubbles were taken for calculation at certain stages of their development

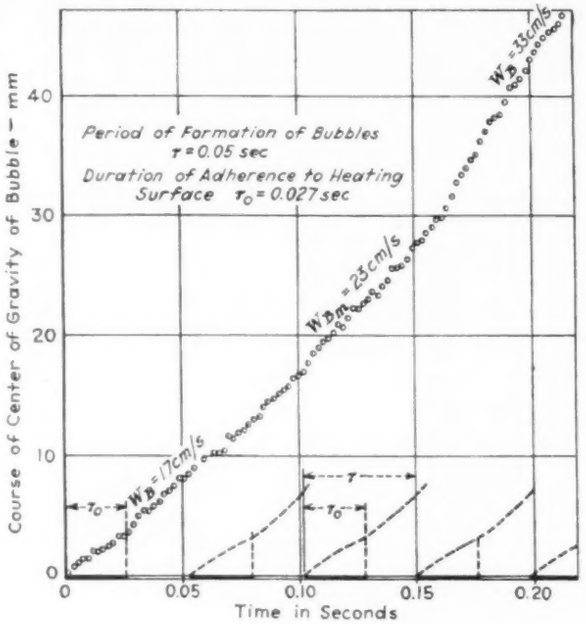
Course of Center of Gravity of Bubble – mm
Period of Formation of Bubbles
τ = 0.05 sec
Duration of Adherence to Heating Surface τ0 = 0.027 sec
W_B = 33 cm/s
W_Bm = 23 cm/s
W_B = 17 cm/s
τ0
τ
Time in Seconds

FIG. 14 COURSES OF BUBBLES AND TIMES REQUIRED TO ASSUME VARIOUS STAGES OF DEVELOPMENT

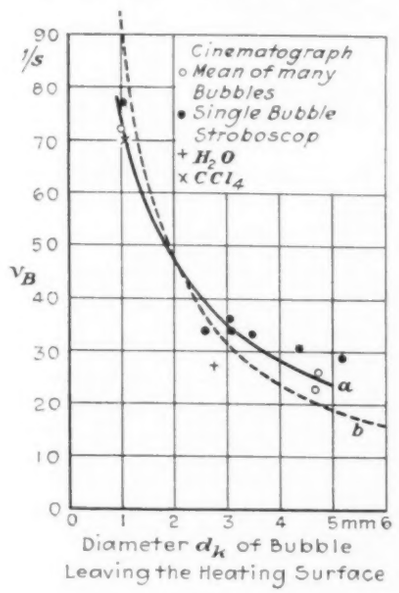

FIG. 15 FREQUENCY OF STEAM BUBBLES

only. For purposes of calculation the pictures, enlarged three to four times, were drawn on a screen.

From these enlargements first the courses of the bubbles and the times required were calculated. An example[16] is given in Fig. 14. In the time $\tau_0 \approx 1/40$ sec during which the bubble adheres to the heating surface, its center of gravity rises with almost the same velocity with which the bubble later rises when it leaves the surface. The mean speed of this rise was $W_{Bm} = 23$ cm per sec in this case. Fritz[2] has calculated the average velocity of six bubbles and has found $W_{Bm} = 26$ cm per sec, the diameters lying between 1 and 8 mm. It may be of interest that Bryn found an average speed of 25 cm per sec for air bubbles rising in water at 18 C.

Returning to Fig. 14, we see that new bubbles originate in intervals of about $1/20$ sec, the frequency therefore being 20 per sec. After each bubble breaks off, marked by a vertical dotted line, a pause of about $1/40$ sec, i.e., half of a period, takes place, during which a new cell of evaporation is formed and the spot where the bubbles originate, cooled slightly by water convection, is heated anew. The frequency of bubble formation depends on the size of the bubbles at the moment of breaking

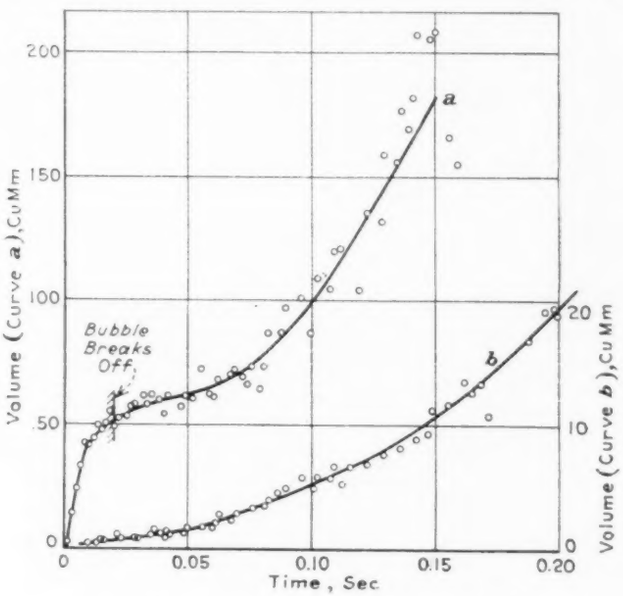

FIG. 16 DEVELOPMENT OF A LARGE BUBBLE

off. Fig. 15 shows the relation between the frequency and the diameter of a sphere of the same volume as the bubble when leaving the heating surface. Before the manner in which this volume is calculated from the results of measurements is described, note that the circles in the present diagram belong to observations on bubbles of 0.5 to 55 cu mm volume at the time of breaking off. The crosses are statistical means of frequency, according to stroboscopic observations on water and carbon tetrachloride, being in sufficient agreement with the cinematographic measurements. A hyperbola, representing only roughly the relation between the equivalent sphere diameter of the bubble and the frequency, is drawn as curve *b*.

The volume of each bubble was obtained by graphical integration, the meridian curve being used as a basis. The determination of the surfaces of the bubbles from the meridian curves caused some difficulties; the contours of these curves were superseded by a discontinuous line consisting of single steps. Rotating this system of steps gave rise to an area which could be calculated quite easily. Treating by this method the meridian curves of bodies of known surface, it was recognized that the calculated surface had to be multiplied by about 0.78 for small bubbles and by 0.81 for larger ones, the probable error being less than 5 per cent. Since a great number of pictures had to be treated, we restricted calculation to this approximation, and even then the calculation required much

[16] M. Jakob, *Zeitschrift des Vereines deutscher Ingenieure*, vol. 76, 1932, p. 1161.

time. This was the reason why the results which I published[16] in 1932 were not completed by W. Fritz[2] earlier than this year. The upper curve of Fig. 16 represents the development of the volume of a large bubble, which grows on the heating surface to 52 cu mm, and then increases up to about 200 cu mm as it rises in the water. When resting on its base the bubble grows much faster than when rising. Apparently, the high temperature of the layer bordering immediately upon the heating surface produces part of this effect, another being in the relation of surface area to volume which is much greater at the beginning. Curve *b* refers to a bubble of mean size, all points relating to the rising stage. The curves depicting increase of the surface of the bubbles are similar to those shown in Fig. 16.

In Table 3 the volumes and surfaces of the six bubbles studied by Fritz are brought together with the times belonging to them.

TABLE 3 INCREASE OF RISING BUBBLES

	Bubble leaving heating surface			Last frame		
Bubble no.	Time, sec	Volume, cu mm	Surface, sq mm	Time, sec	Volume, cu mm	Surface, sq mm
BM1	0.023	83.5	98	0.15	200	241
BM3	0.018	34.5	54	0.136	100	168
BR8	0.020	52.5	69	0.145	172	207
B 0	...	≈0.5	..	0.195	18.5	38.4
B 1	...	≈0.5	..	0.195	27.6	50
B 2	...	≈0.6	..	0.20	28.6	50

Since the temperature of the steam above the water-level surface and that of the water from the heating surface up to

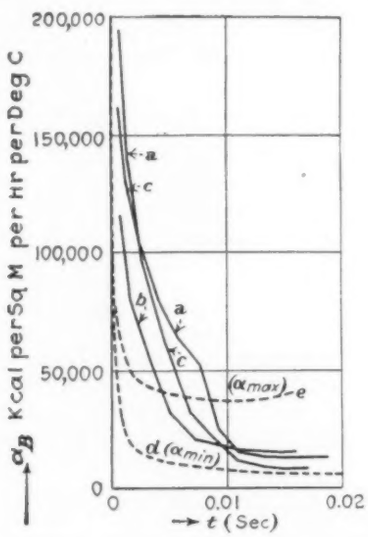

FIG. 17 COURSES OF THREE BUBBLES IN FIRST 1/100 SEC (*a*, *b*, *c* determined from growth of bubbles measured by high-speed camera; *d*, *e* calculated from the propagation of cold wave in surface film of bubble.)

the water-level surface have been exactly measured, all data that enter the Bošnjaković theory are known, and it is possible to calculate the course of the coefficient of heat transfer for the rising bubble and partially, also, for the bubble that is at rest.

To complete the curve relating to two bubbles which I published[16] in 1932, Fritz has now calculated the change of the coefficient α_B with the time for six bubbles.[2] The course of three bubbles in the first hundredth of a second may be seen in Fig. 17 (curves *a*, *b*, *c*). First the extraordinarily high value of α_B (about 200,000 kcal per sq m per hr per deg C, or more corresponding to 40,000 Btu per sq ft per hr per deg F), at the moment of the origin of the bubble is amazing. It has been explained in the following simple manner:[16]

Generally, a steam bubble will be surrounded by a very thin layer of water across which the temperature decreases from the higher value existing in the superheated water to the saturation value. Suppose that a stationary and linear drop of the temperature exists in this layer. Then the coefficient of heat transfer is defined by the equation

$$\alpha_B = \lambda/\delta$$

in which

λ = the heat conductivity of water
δ = the thickness of the thin layer

But at the moment when the bubble originates, this layer does not exist at all. Imagine that by the explosion in microscopic scale which produces the bubble the temperature of its surface decreases immediately, for example, from 110 to 100 C so that δ will be 0 and α a very large value. Immediately, a cold wave sets in and the temperature gradient at the inner surface of the bubble decreases quickly.

A similar problem, relating to an infinite plane, is known, i.e., the case of sudden change of the surface temperature of a plate originally of a uniform temperature to a value that

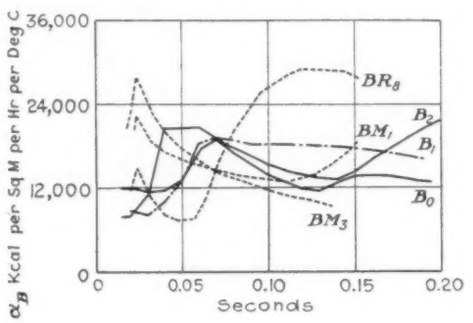

FIG. 18 COEFFICIENT OF HEAT TRANSFER FROM WATER TO STEAM BUBBLES

thereafter remains constant. From this it is recognized that for short intervals almost the entire drop of temperature is concentrated in a thin boundary layer at the surface, this justifying the use of the equation $\alpha_B = \lambda/\delta$. Unfortunately, our case differs from the forementioned simple theoretical case in the fact that the surrounding temperature at some distance of the cooling surface is not constant but is decreasing, since the bubble growing on the heating surface passes from warmer surroundings (immediately at the heater) to colder ones. Fritz has calculated two curves, a minimum curve *d* on the supposition that the variation of the temperature of the surroundings would immediately become effective and a maximum curve *e*, on the supposition that the temperature of the surroundings would remain equal to the temperature of the heater surface. The first curve lies throughout beneath the observed curves and the latter one above them, beginning at about 0.01 sec. But as the bubble must be considered to be growing, the boundary layer will be spread out and will become thinner like an inflated rubber ball. Hence α_B will be greater than the calculated course of curve *e*, this effect decreasing with the increase of the volume, i.e., with the time. At present, it can only be said that the theoretical conception of this problem and the experimental results agree qualitatively; that the quantitative deviations can be understood; and that it seems possible to improve the theoretical treatment of the problem.

Fig. 18 relates to the rising of the six bubbles in the water, the complete time being 0.2 sec and the total height reached by the bubbles 50 mm.

The fluctuations and deviations of the curves of α_B of Fig. 18 are partly caused by the difficulties of evaluation. The mean values for the complete time of rise lie between 13,000 and 22,700 kcal per sq m per hr per deg C, the average being α_B = 16,000 kcal per sq m per hr per deg C, corresponding to 2600, 4540, and 3200 Btu per sq ft per hr per deg F, respectively. It will be recalled that Bošnjaković calculated the value of 36,500 kcal per sq m per hr per deg C for the heat transfer of the bubble, this being too high but not so bad as a first estimate.

6 EVALUATION OF CALORIMETRIC AND THERMOMETRIC MEASUREMENTS

The second principal part of this lecture concerns the evaluation of experiments on the heat transfer between heating surface and boiling fluid. In these experiments two quite different liquids were used in order to study the part the fluid plays in the process. The respective measurements are very simple in principle. They consist merely in determining thoroughly the electrical energy and the temperature of the wall and the water, which had to be measured at different points. But an extraordinary difficulty—similar to one occurring in the case of condensation—arose from the fact that surface conditions and their effect were changing with time.

This we recognized in our very first experiments on the influence of roughness.[11] Figs. 19 and 20 show this in the two kinds of relationships we always used, i.e., Fig. 19, the difference of temperatures $\vartheta_{om} - \vartheta_{wm}$ and, Fig. 20, the coefficient of heat transfer α, both as function of the density of heat flow H. These quantities are related by the familiar equation

$$H = \alpha (\vartheta_{om} - \vartheta_{wm})$$

where ϑ_{om} = the temperature of the heating surface
ϑ_{wm} = the temperature of the water at some distance from the wall.

In Figs. 19 and 20:
The curves 1 (circles) relate to a heating surface, recently roughened by a sand blast
The curves 2 (triangles) relate to the same, oxidized by longer use
The curves 3 (upright crosses) relate to the same, roughened once more by sand blast
The curves 4 (× crosses) relate to the same, after longer use
The curves 5 (reversed triangles) relate to heating surface recently fitted with a screen and cleaned
The curves 6 (squares) relate to the same after four hours of evaporation, then lying in the water for 24 hours
The curves 7 (dots) relate to the same after 8 hours more of evaporation, then another 24 hours of lying in the water.

In curve 5 the coefficient α nearly reached 14,000 kcal per sq m per deg C for H = 25,000 kcal per sq m per hr, which might be caused in part by the 80 per cent increase of area as a result of the grooves which form the screen. The higher position of the curves 6 and 7 as compared with 5, Fig. 19, corresponding to a lower position of the respective curves, Fig. 20, is probably caused by the impoverishment of the surface as regards the number of microcells for evaporation, because the number of air particles, adsorbed by the newly roughened surface decreases during evaporation. This assumption is supported by the observation that the main changes took place when the heating surface remained under water for quite a long period after the experiment. In the following experiment the necessary cells are missing, since the heating surface has given off adsorbed air to water freed of air by previous boiling. The heating plate was subsequently regenerated, by lying in air for a long time, and then very high coefficients α were again obtained.

The same phenomenon, though less pronounced, was later observed with smooth surfaces as well (Fig. 21).[17] Here, from a state I, given by the lower curve Θ, signifying the temperature difference denoted previously by $\vartheta_{om} - \vartheta_{wm}$, or the higher value of α, we succeeded in getting a reproducible stable state II (the upper curve Θ and the lower α), which could not be surpassed. I suppose that in this state the plate was freed of gas to such

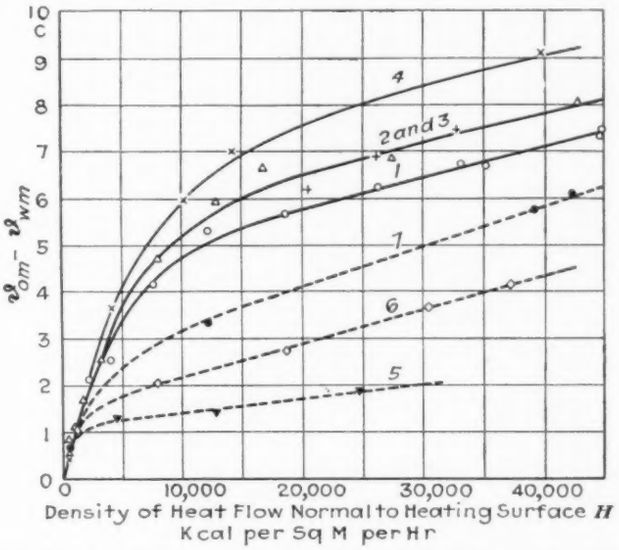

FIG. 19 RELATIONSHIP OF TEMPERATURE DIFFERENCE TO DENSITY OF HEAT FLOW H FROM HORIZONTAL ROUGH HEATING SURFACES

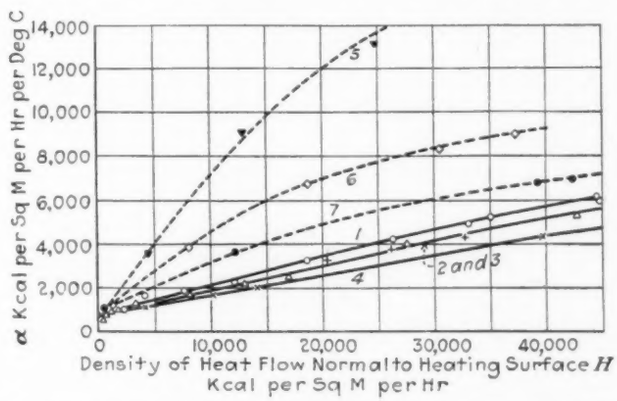

FIG. 20 RELATIONSHIP OF COEFFICIENT OF HEAT TRANSFER TO DENSITY OF HEAT FLOW H FROM HORIZONTAL ROUGH HEATING SURFACES

an extent that only tiny cavities, filled with steam, incited the evaporation. In this case not only the regeneration of the plates in air from II to I could be obtained, but also the reverse transition from I to II always took place when the heated plate was kept for a longer time in water freed of air by boiling. The number of steam columns on the plate was smaller in state II than in state I.

Unfortunately, it was not possible to get a perfectly stable state II with heaters, built later, but back strokes took place, especially in experiments with carbon tetrachloride. Pos-

[17] M. Jakob and W. Linke, *Forschungsarbeiten auf dem Gebiete des Ingenieurwesens*, vol. 4, 1933, p. 75.

sibly the back strokes were the first symptoms of the deterioration of the heater bodies, occurring later as a consequence of formation of copper oxide on the surface. In any case, we based our calculations on the smallest observed values of α, these seeming the most stable ones.

Although in Fig. 21 states I and II are represented only for a horizontal plate, the behavior of a vertical surface is shown in Fig. 22. Curves 1 to 6 illustrate experiments which covered the period of a month. During this time the cylinders were

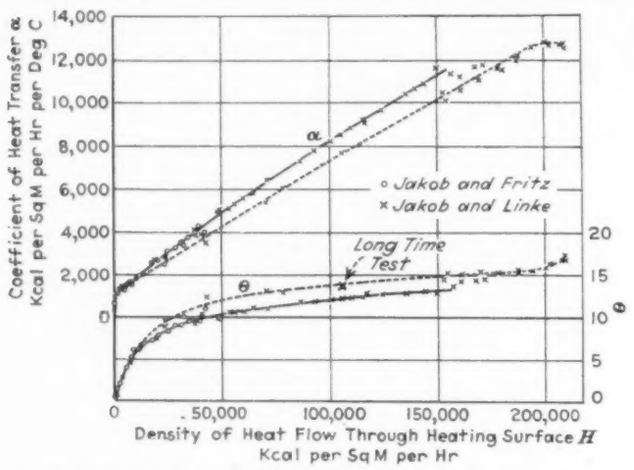

FIG. 21 RELATIONSHIP OF COEFFICIENT OF HEAT TRANSFER TO DENSITY OF HEAT FLOW H FROM A HORIZONTAL SMOOTH HEATING SURFACE

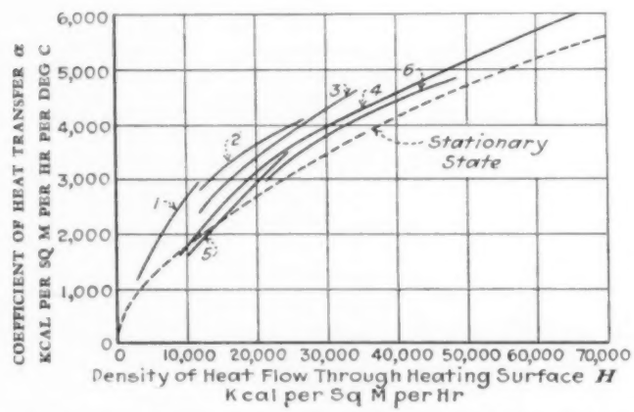

FIG. 22 RELATIONSHIP OF COEFFICIENT OF HEAT TRANSFER TO DENSITY OF HEAT FLOW H FROM A VERTICAL SMOOTH HEATING SURFACE

(1–6 = order of experiments.)

not removed from the water. The stable state is represented by the dotted line.

There is still another difficulty to overcome with vertical surfaces. While with horizontal plates it is possible to obtain the same temperature over the entire plate, in vertical cylinders this can be done only for a lower heat flow H. In the latter case the difference of temperature Θ between surface and fluid increases from the lower end upward until it reaches a maximum value and then decreases slightly. This is the well-known course of Θ in natural convection. On the contrary, Θ decreases from below to above when H has a high value. For, apparently, the stirring effect of the rising steam bubbles becomes more vigorous from the lower end toward the top.

The result of our experiments with water and carbon tetrachloride for horizontal and vertical heating surfaces is recorded in Fig. 23. Fig. 23 shows that the coefficient α for water is about 2.5 times as great as that for carbon tetrachloride. The diagram further shows the important fact that the heat transfer from a vertical cylinder, dotted lines, is nearly the same as for the horizontal plate, at least for heat-flow densities as high as 60,000 kcal per sq m per hr, corresponding to about 22,000 Btu per sq ft per hr, this being the upper limit we reached, as previously mentioned. It should be further noted that above $H = 200{,}000$ kcal per sq m per hr, corresponding to about 74,000 Btu per sq ft per hr, α remains constant for water. In this region the number of steam bubbles formed on the plate becomes so large that the bubbles disturb one another as to their stirring effects. We even observed a drop in α when increasing the heating energy still more. This, of course, was connected with a rapid rise of temperature, soon leading to a burning through of the heating resistance.

Finally, the steep course of the two curves for water near the zero point of the system is striking. We shall see that the law of heat transfer for small loads differs from that for large ones.

Since evaporation is a process connected with surface phenomena, we compared two substances of as different surface

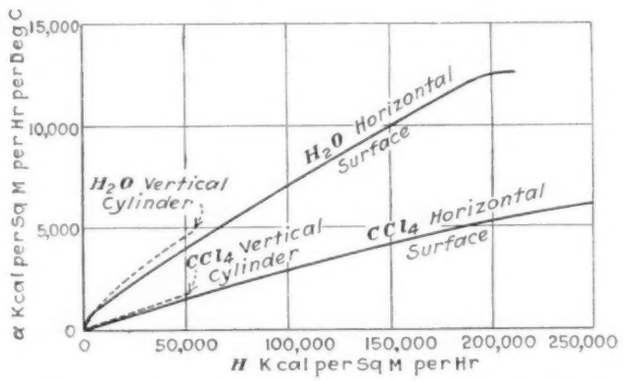

FIG. 23 COEFFICIENT OF HEAT TRANSFER FOR VAPORS OF H_2O AND CCl_4

tension σ as H_2O and CCl_4 ($\sigma = 6.00 \times 10^{-3}$, and 2.06×10^{-3} kg per m, respectively). Moreover, we used a solution of an organic substance (Nekal BX) in water, varying the surface tension greatly without affecting the other properties of water. Adding 1 per cent of Nekal to water, σ drops from 6.0×10^{-3} to 2.8×10^{-3}, and only slightly thereafter. Experiments with $H = 34{,}800$ kcal per sq m per hr showed that, lowering σ from 6.0×10^{-3} to 3.32×10^{-3}, the temperature drop from the plate to water decreased from 10 to 8.1 C. Accordingly, by addition of 0.5 per cent Nekal, the coefficient α increases by 23 per cent. A practical application of this fact seems to be difficult because of deposits and foam.

We further varied the relative dimensions of the vessels, but no considerable change took place. Likewise, the height of the water level did not remarkably influence the coefficient α except below 5 mm, where α rose rapidly.

Apart from this, we wanted some more data for the theoretical evaluation of our experiments. By means of the stroboscopic measurements previously mentioned, we determined that the most frequent diameter of bubbles as they left their bases was about 2.8 mm for water and 1.1 mm for CCl_4 and the respective frequencies about 27 and 70 per sec. The product of diameter and frequency has the constant value of 76 or 77 mm per sec, which is in sufficient agreement with the high-speed-camera experiments giving 72 to 100 mm per sec. Finally, we

studied the manner in which the number of steam columns varied with the depth of the water.

7 DIMENSIONLESS REPRESENTATION OF HEAT TRANSFER IN EVAPORATION

The third and last part of this lecture deals with the theoretical comprehension of the results of our experiments, and is greatly facilitated by the application of dimensionless analysis.[8]

With a slight amount of heating the stirring effect is negligible compared with the motion by free convection. Therefore, in this region the laws of natural convection will hold good. The general form of these laws is given by

$$\mathrm{Nu} = \phi\,(\mathrm{Gr}, \mathrm{Pr}) \approx C(\mathrm{Gr}\cdot\mathrm{Pr})^m \quad [17]$$

in which

$\mathrm{Nu} = \dfrac{\alpha l}{\lambda}$ = the Nusselt number

$\mathrm{Gr} = \dfrac{l^3\gamma^2\,\beta\theta}{\eta^2\,\alpha}$ = the Grashof number

$\mathrm{Pr} = \dfrac{c_p\eta g}{\lambda}$ = the Prandtl number

l = characteristic length
α = coefficient of heat transfer
g = acceleration due to gravity
γ = specific weight of the fluid
β = coefficient of thermal expansion of the fluid
η = dynamic viscosity of the fluid
c_p = specific heat of the fluid
λ = heat conductivity of the fluid

The results of the known experiments conducted with single-phase systems are collected in Fig. 24, where the representation, suggested by Nusselt, has been chosen, the abcissas being Gr·Pr and the ordinates Nu, both in the logarithmic scale. Most of the points are taken from a paper by King.[18] In addition we entered the results of our own experiments on water and carbon-tetrachloride evaporated from horizontal and vertical plates.

According to Fig. 24 two laws of convection exist, the first

$$\mathrm{Nu} = 0.56\,(\mathrm{Gr}\cdot\mathrm{Pr})^{1/4}$$

relating to streamline motion, and the second

$$\mathrm{Nu} = 0.13\,(\mathrm{Gr}\cdot\mathrm{Pr})^{1/3}$$

to turbulent motion.

In the region up to about $\mathrm{Gr}\cdot\mathrm{Pr} = 10^9$, our experiments with vertical cylinders correspond to the first law, and those with horizontal plates to the second, the constants C being somewhat higher than those holding for single-phase experiments, as can be seen from Fig. 24 ($C = 0.61$ instead of 0.56; $C = 0.16$ instead of 0.13). It is easily understood that in the case of the vertical surface, the rising convection flow, being parallel to the surface, smooths, as it were, the flow near the wall, while a course perpendicular to the horizontal plate will disturb the boundary layer and lead to turbulence. Therefore, our experiments on boiling liquids correspond generally to the results obtained with single-phase systems.

While this holds good up to $\mathrm{Gr}\cdot\mathrm{Pr} \approx 10^9$, at higher values our lines deviate from the straight lines representing the laws of free convection as the stirring effect of the bubbles begins and the laws of forced convection become effective. Qualitatively, it will be recognized that the heat transfer represented by the Nusselt number is rising much more rapidly. Moreover, in this region the curves for horizontal and vertical surfaces, as well as those for water and carbon tetrachloride, differ greatly from each other, the relationship in Fig. 24 being far from any law of similarity.

Now I should like to explain how we tried to obtain a new dimensionless relation for this region also, based only on a simple physical concept.

In the following equations n signifies the number of vapor columns, ν the frequency of bubbles in such a column, and d_u the mean diameter of the bubbles leaving the heating surface. The portion f of the heating surface F which is occupied by bubbles is given by

$$f = n d_u^2\,\pi/4 \quad [18]$$

The volumes of the bubbles leaving the base and reaching the water-level surface are given by

$$V_u = d_u^3\,\pi/6 \quad [19]$$

and

$$V_0 = d_0^3\,\pi/6 \quad [20]$$

respectively.

The following approximate equation

$$V_0/V_u \sim \sqrt{h} \quad [21]$$

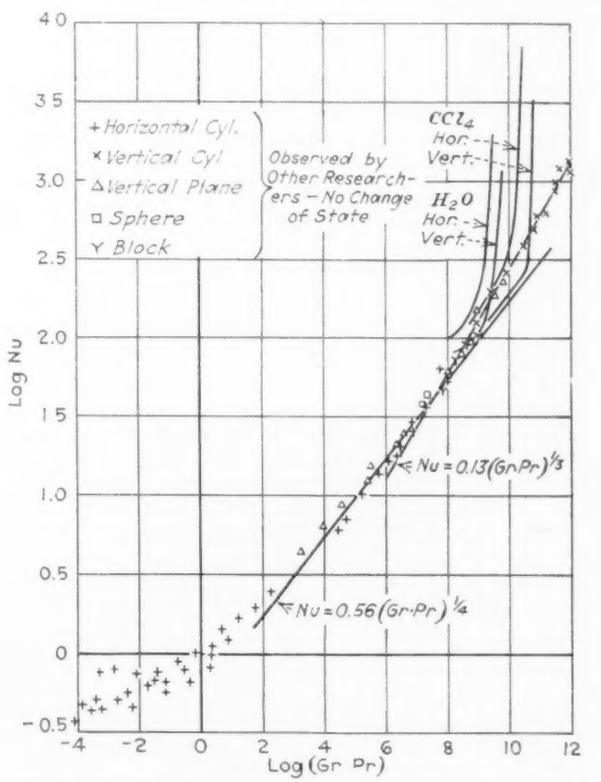

FIG. 24 DIMENSIONLESS REPRESENTATION OF HEAT TRANSFER (Suitable within range of free convection.)

is deduced from cinematographic experiments. Now, the ratio f/F is essential for the motion of the fluid on the heating surface, because the portion f of the area F is occupied and abandoned by the bubbles in continual change, thus sweeping the heating surface. A second quantity important for the motion of the fluid is the displacement of water by the rising bubbles. The stirring motion will be the more vigorous the more

[18] W. J. King, *Refrigerating Engineering*, vol. 25, 1933, p. 83.

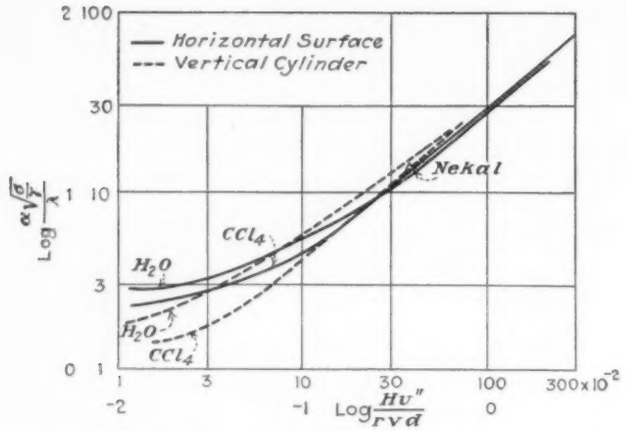

FIG. 25 DIMENSIONLESS REPRESENTATION OF HEAT TRANSFER (Suitable in range of stirring effect of vapor bubbles.)

the volume of the rising bubbles increases. Thus we assume

$$\mathrm{Nu} = \frac{\alpha l}{\lambda} = \Psi\left(\frac{f}{F}\frac{V_0}{V_u}\right) = \Psi\left(\frac{f}{F}\sqrt{h}\right) \quad [22]$$

By substituting [19], [20], and [21] and multiplying by ν above and below we get

$$\frac{f}{F}\frac{V_0}{V_u} = \frac{3}{2}\frac{n}{F}d_0^3\frac{(\pi/6)\nu}{d_u\nu} \quad [23]$$

Further, it will be easily understood that the total volume of steam formed in unit time above the unit area of the heating surface will be

$$\frac{n}{F}d_0^3\frac{\pi}{6}\nu = \frac{H}{r}v'' \quad [24]$$

Substituting [24] ~~and [25]~~ in [23] ~~gives~~ in (22) gives

$$\frac{\alpha d_u}{\lambda} = \Psi\left(\frac{Hv''}{r}\frac{1}{d_u\nu}\right) \quad [25]$$

Now, according to the theory of formation of bubbles, with the mean contact angle found to be about 50 deg and using the data of Fritz, we have

$$d = 1.034\sqrt{\sigma/\gamma} \quad [26]$$

Further, from stroboscopic and cinematographic measurements

$$d_u\nu = w \approx 280 \text{ m per hr} \quad [27]$$

Substituting [27] and [~~25~~ 26] in [~~26~~ 25] we get, generally

$$\mathrm{Nu} = \frac{\alpha}{\lambda}\sqrt{\frac{\sigma}{\gamma}} = \Psi\left(\frac{Hv''}{rw}\right) \quad [28]$$

and from our calorimetric measurements, the special form of this equation

$$\mathrm{Nu} = \frac{\alpha}{\lambda}\sqrt{\frac{\sigma}{\gamma}} = 30\left(\frac{Hv''}{rw}\right)^{0.8} \quad [29]$$

This function is represented in Fig. 25, which shows that within the range of the stirring effect of the vapor bubbles a single straight-line relation holds for the experiments with horizontal and vertical surfaces for water and CCl_4, and for solutions of Nekal in water, this being signified by the small triangle. In this diagram it will be noted that a law of similarity holds for the upper region while the lines diverge in the lower part, the former law (Nu depending on Gr·Pr) being effective.

Finally, I should like to stress once more, that, owing to the great extent of the field I am discussing, I cannot even mention experiments on evaporation by other researchers, such as the interesting ones by Cryder and Gilliland in this country, or those by E. Schmidt and his coworkers on the circulation of water in boilers. But I hope that even without such a survey of the existing literature, I shall have succeeded in giving in these three lectures some insight into the objectives of the problem of evaporation, and of the manner in which I attacked several bulwarks of it in cooperation with my former coworkers.

Ewing Galloway, N. Y.

ENGINEERING PROGRESS

A Review of Attainment in Mechanical Engineering and Related Fields

BECAUSE the editor of this section, who has abstracted the articles that have appeared in it since the establishment, in 1912, of the "Foreign Review" as it was then called, is on leave of absence, space devoted to the abstracts has been reduced.—EDITOR.

ENGINEERING MATERIALS

Microporite

MICROPORITE is a new ceramic material made in the form of a hydrated calcium silicate. The general process of manufacture is explained in the original article. The material has voids amounting to about 75 to 80 per cent of the space occupied. These voids are, however, so small that they are not visible under a microscope. It has compressed strength of as high as 1000 lb per sq in. and a unit weight of 25 lb per cu ft. The maximum flexural strength runs about one fifth and the tensile about one tenth of compressive strengths. The heat transmission is 0.70 Btu per hr per sq ft per deg F per in., at the unit weight of 29 lb per cu ft and a mean temperature of 70 F. The increase in transmission with increasing temperature is very small.

A prefabricated house has been assembled of units which are made from this material and is described in the original article.

This type of building has comparatively few joints, so that it is extremely important to insure a large amount of flexibility in these joints. When all the discussion appearing during the past few years about mortar joints, where units are only about 10 sq in. in area, is remembered, it is evident that this sudden jump in unit area to 4500 sq in. or 450 times, throws much greater stresses upon the joints, and this must be, and is, taken care of by providing flexible joints of demonstrated durability. The roof is of standard bituminous-felt construction.

This four-room house may be built as a single dwelling, or it may be built up and out into any number of apartments as desired. While no apologies need be made for the appearance of this small unit house it is much easier to design a very attractive residence having a second story, while combinations into multiunit dwellings permit wide latitude in securing dignified and handsome architectural results. (F. O. Anderegg in *Rock Products*, vol. 39, no. 5, May, 1936, pp. 48–51, 6 figs.)

INTERNAL-COMBUSTION ENGINEERING

Comparative Investigation of Combustion and Working

IT IS only the perfection of new apparatus and methods for measurement and observation of what goes on in the cylinders of an internal-combustion engine that made possible such an investigation as the one abstracted here. Only comparatively brief abstracts of the main subjects investigated are possible.

PRESSURE VARIATIONS IN THE CYLINDER

In the Diesel engine with direct injection investigated by the author combustion starts with a rapid and powerful increase in pressure, while in a Diesel engine with a subdivided combustion chamber a milder ignition with lesser increase in pressure is observed. With direct injection at full load the maximum pressures in general exceed 80 atm while in turbulence-chamber and air-storage Diesels they vary only from 55 to 65 atm. and are still lower in precombustion-chamber engines.

In the case of direct injection, softer combustion with slower rise of pressure can be obtained by later injection and longer duration of injection; however, these will be accompanied by increased consumption of fuel, because of incomplete combustion. This is illustrated in the original article.

In ignition engines the combustion starts with normal ignition setting before the piston reaches the upper dead center. The process of combustion is discussed next, and the author shows how, if the weight of the charge of fuel in the cylinder is known, it is possible to calculate from the indicator diagram the sum of the heat passing from the gas to the wall and that of the fuel as yet unconsumed. The author gives an equation for the sum of these quantities of heat.

PROCESSES OF COMBUSTION ACCOMPANYING VARIOUS WORKING PROCESSES

In ignition engines the combustion occurs with great rapidity and takes place in the neighborhood of the dead center. The peak pressures, however, because of the low compression ratios, are smaller than in Diesel engines. Rapid combustion in the neighborhood of the dead center is not desired in a Diesel engine because it is accompanied by very high pressures without a corresponding increase in the power output. On the other hand, however, the main part of the combustion should not run over deeply into the expansion stroke as this decreases both the efficiency and the average pressure.

In the case of Diesel engines working with subdivided combustion chambers throttling often occurs between the main cylinder chamber and the auxiliary chamber and this throws out all calculations. The author shows how to handle this problem.

In the case of a given compression ratio and a given fuel, the beginning of combustion is determined substantially by the beginning of injection and because of this the duration of combustion is a function of the duration of injection and the shape of the nozzles. In a majority of cases, the process of injection is still going on when combustion starts, as a result of which the fuel injected under these conditions burns with a smaller ignition lag on account of the high temperature prevailing in the cylinder. This gives the designer a means of influencing to a certain material extent the process of combustion, although, particularly in the case of low-compression engines, it is not always possible, because of great lag in ignition used to induce combustion to start before the end of the injection process. Since the weight of the gas in the cylinder corresponding to the equation of state and the gas constant vary during the combustion, it is necessary to precalculate exactly the amount of fuel by taking into consideration the composition of the gases and their dissociation.

The unconsumed fuel at the beginning of combustion is present partly in the form of a vapor (in an ignition motor, for example) and partly in the form of liquid particles. While the weight of the particles of liquid does not appear in the equation of state, the gaseous fuel makes it necessary to introduce a variation in the gas constant. Furthermore, since, according to recent investigations, in an ignition motor of average characteristics the gasoline is practically completely vaporized at the beginning of combustion, the possible error due to improper consideration of the liquid part of the fuel is in the case of ignition motors less than 1 per cent. In the Diesel engine the vaporized portion of the fuel is unimportant and hence is not considered.

The section dealing with the influence of ignition lag on the working process in a Diesel engine is not abstracted, nor are the two sections dealing with the functional relationship between the average and maximum pressure in the cylinder and the consumption of the fuel, and the investigation of the method of operation of the various Diesel-engine working processes.

The conclusion to which the author arrives is that in the region of loads corresponding to continuous operation a material increase in average pressure in a Diesel engine cannot be produced as readily through an improvement in the process of operation as through improvements in filling the cylinder, in scavenging, or in improvement in the valve gear.

At maximum load with small excess of air, it is possible to raise the average pressure and the limit of smoking by improving the turbulence of the air. In the case of ignition motors there is a limited possibility of increasing the average pressure and simultaneously improving the fuel consumption by employing a higher compression and a nondetonating fuel. The best way to improve the output, however, both in the Diesel and in motors of the ignition type is by supercharging. In the case of the Diesel engine, supercharging helps chiefly because the reduction of efficiency in the proximity of the region of excess of air $\lambda = 1$ can be avoided with a greater excess of air. Furthermore, the mechanical efficiency is improved on account of the higher indicated output with a smaller increase in friction. This is illustrated by a reference to the Büchi exhaust-gas turbine. An increase in compression in the case of a Diesel motor has a limit of about $\epsilon = 18$, because it cannot be expected that the consumption will be materially improved on account of the increased friction. An effort has been made to reduce the ignition lag by a better precompression of the fuel mixture, because, at the compression temperatures, which correspond to the usual range of compression in Diesel engines, the influence of temperature on the ignition lag is small as compared with the influence of density, and hence the ignition lag is reduced by precompression to the same extent as by a rise in the compression ratio.

In all Diesel processes using a subdivided combustion space, at normal operation, combustion is observed in the prechamber or in the storage reservoir with delivery of ignited gases into the main cylinder chamber. The differences between the various processes lie primarily in the various conditions of flow, presence or absence of turbulence, and the temperature of the walls. The ignition process is favorably affected by hot throttle spots. (Dr. Fritz A. F. Schmidt in *Zeitschrift des Vereines deutscher Ingenieure*, vol. 80, no. 25, June 20, 1936, pp. 769–779, 22 figs.)

MACHINE-SHOP PRACTICE

Mechanical Investigation of Forgability of Various Types of Light and Ultra-Light Alloys

THE purpose of this investigation has been to determine precisely the best condition for hot-working of aluminum and certain aluminum alloys. As the tendency toward hot rupture is a function not only of the character of deformation but also of the velocity of deformation, the author considered two groups of tests, namely, static tests in bending and compression at various temperatures with records of diagrams of stress deformation, and dynamic tests in bending and tension at various temperatures, but without recording the diagrams.

The result which the authors obtained from their experiments is that alloys of magnesium are capable of being cut up to a content of 15 per cent of copper, or 6 to 9 per cent of aluminum. If handled carefully they can be forged up to 15 per cent of copper content. As regards aluminum alloys, those containing 12 per cent of copper can be either cut or forged with proper care; in the case of aluminum-magnesium alloys the limit of forgability is between 5 and 10 per cent of magnesium, if the metals used in the composition of the alloy are pure. (Albert Portevin and Paul Bastien in *Comptes Rendus des Séances de l'Academie des Sciences*, vol. 202, no. 25, June 22, 1936, pp. 2072–2074, 2 figs.)

REFRIGERATION

Vacuum Refrigeration

THE author discusses recent improvements in the steam-jet vacuum producer. He gives curves showing actual operating data with figures for steam and water consumption at different chilled-water and condenser-water temperatures, and also reports certain experimental data where the vacuum evaporating chamber was tested under its full range of working conditions to insure that there had been sufficient contact of the water with the vacuum so that the water leaving would be chilled completely to the temperature corresponding to the vacuum.

Many plants have a surplus of exhaust steam at atmospheric pressure or slight positive pressure, particularly in summer when refrigeration is most necessary. The steam-jet type of cooling equipment has been adopted for using this exhaust steam even though it has no positive pressure above atmospheric. When the proper vacuum is maintained in the main condenser, this atmospheric-pressure steam develops sufficient velocity through the jets to give practical and economical results for many conditions. Of course, steam consumption is greater when using low-pressure steam. The quantities required at pressures down to atmospheric were determined but are not available for publication.

Vacuum refrigerating equipment has considerable flexibility. Accurate tests indicate that any unit designed for a definite chilled-water temperature can be operated at a variety of different chilled-water temperatures at different capacities; for example, a unit designed to produce 100 tons of refrigeration at a chilled-water temperature of 50 F will automatically produce 115 tons of refrigeration at a chilled-water temperature of 55 F. If the chilled-water temperature is lowered instead of raised, the capacity is also lowered; at a chilled-water temperature of 40 F the capacity drops to 70 tons, and to 55 tons with a chilled-water temperature of 35 F. Conversely, a unit designed for operation at a relatively low temperature will provide increased heat-absorption capacity when operated at slightly higher temperatures. (D. H. Jackson, Croll-Reynolds Co., Inc., New York, N. Y. In *Industrial and Engineering Chemistry*, vol. 28, no. 5, May, 1936, pp. 522–526, 5 figs.)

LETTERS AND COMMENT

Brief Articles of Current Interest, Discussion of Papers, A.S.M.E. Activities

Steam-Turbine Testing

IN A PAPER on "Steam-Turbine Testing" by C. Harold Berry, which was published in the November, 1935, issue of MECHANICAL ENGINEERING, it was proposed that hereafter turbine test methods should call for the measurement of the impact pressure and temperature of the entering steam and the impact pressure of the exhaust steam. It was contended that this was a correct method, and that the use of static values was incorrect. It was further contended that the impact values could be measured with somewhat higher precision and perhaps more easily. It was conceded that the numerical change in final results would be small, but this was no argument, since the change was in the direction of a closer approach to truth and fairness, and since it was common to make provision for determining other quantities that were no larger.

The discussion of this paper in condensed form, and the author's closure, follow:

FRANK O. ELLENWOOD.[1] The chief objection to the proposal is with reference to the ideal turbine. Heretofore we have always treated all ideal engines as though the time element were of no significance; the rate of flow need not be considered. This seems to be logical. I believe that the ideal turbine should be defined as one that allows no loss of kinetic energy with the exhaust steam.

Whether impact or static pressure should be measured at entrance is another question. I believe that the energy supplied to both a real and ideal turbine should be the aggregate value. If impact pressures can be measured more accurately and conveniently than static at entrance and exit, then let us measure that way. The actual velocities and the static pressure at exhaust can readily be found from curves (Professor Ellenwood showed a slide giving such curves for an assumed case). Let us not change our standard of comparison to one that is less logical simply because it may be easier to determine an impact pressure.

E. F. CHURCH, JR.[2] I approve of the proposal because I do not believe we should agree to neglect the kinetic energy of the steam supplied just because it is now thought to be more difficult to measure the impact values, or because this kinetic energy may, under special conditions, be practically canceled by kinetic energy at another point in the flow. The case seems otherwise at the exhaust end. The opportunity is offered to the turbine to expand the steam to condenser pressure and to deliver it to the condenser with negligible kinetic energy. It is the fault of the turbine if it does not accomplish this. I hope that no system to be adopted for measuring the opportunity offered to the turbine will include a credit for the high-grade kinetic energy carried away by the steam as it flows from the turbine exhaust.

G. B. WARREN.[3] My primary objection is that I think we should be going in the direction of further simplification rather than toward greater complication in testing. Our pressing need is for more, not fewer tests on large turbines. The present obstacle to tests is the cost to the user and the manufacturer, and the interruption of the operating schedule. The test of actual turbines in the field is the final testing laboratory of the manufacturer. If the art is to progress, the designer must know how his expectations are realized. I feel that the accuracy to be obtained from static measurements is sufficient for present needs.

B. O. BUCKLAND.[4] It is reasonable and proper to take the energy supplied to a steam turbine as the sum of the kinetic energy and the enthalpy, but I do not agree that the most convenient and accurate method of determining this kinetic energy is by means of an impact tube. A single impact-tube reading may show errors of 50 to 100 per cent of the kinetic energy. A traverse would be necessary. A more trustworthy approximation to the kinetic energy would be that determined from flow, static pressure, and temperature. It is true that static pressures are difficult to measure when stream velocity and direction are unknown, but the average static pressure at the exhaust flange is easier to determine than the integrated kinetic energy of the steam. With reference to the ideal turbine, the allowance of a kinetic-energy loss, through using impact exhaust pressure, seems to be neither as useful nor as convenient as the present convention using the average static pressure. In comparing the performance of real turbines, it seems more desirable to use as a measure the ideal turbine with no kinetic-energy loss in the exhaust. The turbine designer strives to produce a maximum number of kilowatts at the shaft and a minimum of kinetic energy in the exhaust stream.

FRANCIS HODGKINSON.[5] The argument is more concerned with exhaust-pressure measurements. Steam-inlet velocities are low, and impact-pressure excesses will usually be within the limits of error. Exhaust conditions are different; the velocity is high and highly variable.

So far as I know, no contract or specification has ever been written which states whether static or impact exhaust pressure is intended. The author has shown that there is material difference between them. Consideration of the effect of a hypothetical diffuser on the turbine exhaust seems to lead to the conclusions that the impact pressure should be specified and observed.

Analysis or trial might show that, so far as fairness is concerned, it does not matter much which kind of pressure is employed so long as one or the other is specified and codified.

Shall it be assumed that the available energy which the turbine has to make the best of includes the available energy

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[2] Professor of Mechanical Engineering, Polytechnic Institute of Brooklyn, New York. Mem. A.S.M.E.

[3] Design Engineer, Turbine Department, General Electric Company, Schenectady, N. Y. Mem. A.S.M.E.

[4] General Electric Company, Schenectady, New York. Jun. A.S.M.E.

[5] Consulting Mechanical Engineer, Westinghouse Electric & Mfg. Company, South Philadelphia Works, Philadelphia, Pa. Mem. A.S.M.E.

up to the time the exhaust steam comes to rest at the specified pressure? I think it should, and that means that an impact-pressure measurement is the fair and proper one. It also means that the ideal engine has zero exhaust velocity.

I agree that impact-pressure measurements are probably more consistent over the exhaust area than static-pressure measurements. That, however, is no reason for selecting impact measurement unless it is fair and proper.

An exhaust-pressure measurement is probably the most uncertain one in a turbine test. This difficulty and the question raised by the author would be eliminated if condensers were installed under the same contract as the turbine, as is often done in Europe. In this case guarantees are based on circulating-water temperature when exhaust pressure becomes irrelevant to both the contract and the test.

P. H. HARDIE.[6] Virtually all turbines discharge downward, which means that the impact tubes must point upward. What can be done to prevent the impact tubes from filling with water, thereby vitiating the readings? Blowing the lines before each reading is impractical. A drain hole on the lower side of each tube might serve, but the hole must be small to avoid distortion of readings, and there would be doubt of its adequacy as a drain, and possibility of clogging. Lowering the manometers and keeping the line full of water has many obvious disadvantages.

I believe that the impact pressure in the turbine exhaust will be less uniform than the static pressure. The entrained moisture in the steam leaving the last row of turbine blades is stratified, and the kinetic energy of water moving at approximately the same velocity as the steam will produce a very high reading. Tests at the Hudson Avenue Station show reliable static-pressure measurements can be obtained at any position in the exhaust nozzle if a proper tip is used.

I doubt the wisdom of the proposed modification of our present concept of the ideal engine. While the impact pressure in the steam supply can be easily measured and undoubtedly should be used, a similar measurement in the exhaust presents major difficulties. The kinetic energy of the exhaust steam is a turbine loss included by the simple procedure of using the static exhaust pressure in appraising turbine performance.

A. EGLI.[7] It seems that the only incorrect thing in the steam-turbine test code is the combining of static pressure with impact temperature at the turbine inlet. It appears natural that the kinetic energy of the steam supplied should be included in the energy available, since it can actually be used by the turbine, but it appears to the writer that it is not just to credit the turbine with the kinetic energy of the exhaust steam, thereby transferring this loss to the condenser. It is the duty of the turbine exhaust end to deliver steam with a minimum kinetic energy, i.e., an average static pressure as high as possible.

The writer suggests that various standard methods be agreed upon, taking account of such practical difficulties, as

(1) A cheap method using static-pressure taps in the exhaust-conduit wall near the exhaust flange

(2) A more elaborate method, using impact tubes near the exhaust-conduit walls, rotatable about axes perpendicular to the walls

(3) A most elaborate method, using impact tubes distributed over the entire exhaust area, arranged so that they can be oriented in any direction.

In each case the results would be based upon average static pressure, with agreed restrictions on discrepancies, velocity distribution, or the like.

No satisfactory method has yet been devised for measuring the impact pressure of wet steam. There is difficulty in draining accumulated moisture.

J. R. CARLTON.[8] The use of impact tubes is beset with practical difficulties. Location in the pipe necessitates a traverse, a difficult matter, in the steam-supply pipe, especially for higher pressures, and of greater difficulty in the exhaust.

Temperatures measured with unshielded thermometer wells are impact temperatures but the wiping action of high-velocity steam tends to improve heat transfer and, to a considerable extent, prevents the well from having a temperature higher than that of the steam.

The impact temperature and pressure excesses over static values are within the limits of error of measurement, or nearly so. The small leaving loss in the exhaust of the real machine is usually counterbalanced by the kinetic energy of the throttle steam, leaving the ideal engine criterion practically unaffected by kinetic energy. The exhaust kinetic energy is often large enough to be included in computations of true exhaust-steam quality and the turbine-condition curve, but there seems to be no good reason for other applications.

The proposed change is opposed. There is no justification for crediting the turbine with the kinetic energy of its exhaust steam. The use of impact pressures is entirely inappropriate to condenser tests, and their use for the turbine might give rise to confusion.

JOHN J. GROB.[9] The proposed measurement would seem to offer a theoretical refinement in the accuracy of determining performance, but its hasty adoption might introduce instrumental errors of greater magnitude than the refinement sought. Whether the use of impact pressures does or does not increase the probable accuracy of results, it would most assuredly fail to promote convenience. At entrance to the turbine it would be a difficult and expensive job to provide sufficient openings to traverse the area without weakening the fitting and to arrange connections so that an impact tube fitted with a thermocouple might be moved and even waggled about.

In the limited time which was available to us for obtaining field measurements we made an exploratory traverse along a line 45 inches long in the exhaust passage of a 160,000-kw turbine. The familiar type of pitot tube was used, with pinhole static openings and conical impact opening. Readings were taken at four points at a load of 110,000 kw. At each point the pitot tube was rotated to give readings in eight positions.

The results are presented in Table 1 and Figs. 1 to 6.

With the tube facing the stream it is placed in position 1. When it is rotated to positions 3 and 7 the impact tube should be reading static pressures and in this test it does check static closely.

The static tube pinhole openings are apparently too small to be visibly influenced by impact pressures as it duplicates its static-pressure indications even when facing the stream. We have not attempted to evaluate the performance value of these data since they represent such a small portion of the exhaust area.

However it is quite evident that the procedure would be a costly one involving many observers and instruments in order not to prolong a block load on a unit in service operation while the traverse is undertaken.

Fig. 3 shows another traverse on the same unit at about the same load indicating more turbulent steam conditions. Fig. 4 is still another traverse at the same load showing a somewhat different behavior of the steam.

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[6] Test Engineer, Brooklyn Edison Company, Brooklyn, New York, N. Y. Mem. A.S.M.E.

[7] Experimental Division, Westinghouse Electric & Manufacturing Company, South Philadelphia Works, Philadelphia, Pa.

[8] Public Service Electric and Gas Company, Irvington, New Jersey. Mem. A.S.M.E.

[9] Engineer of Tests, New York Edison Company, New York, N. Y. Mem. A.S.M.E.

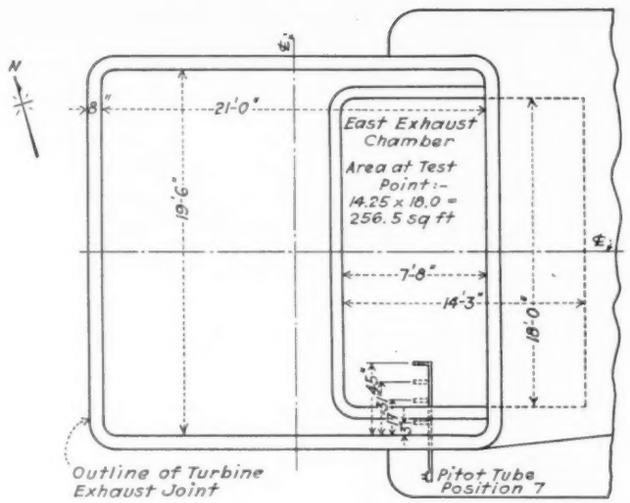


FIG. 1 PLAN OF EXHAUST CHAMBER INDICATING THE TRAVERSING LINE

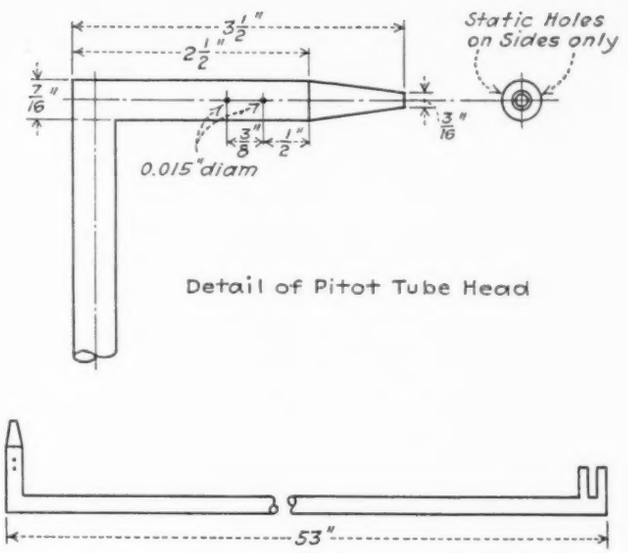
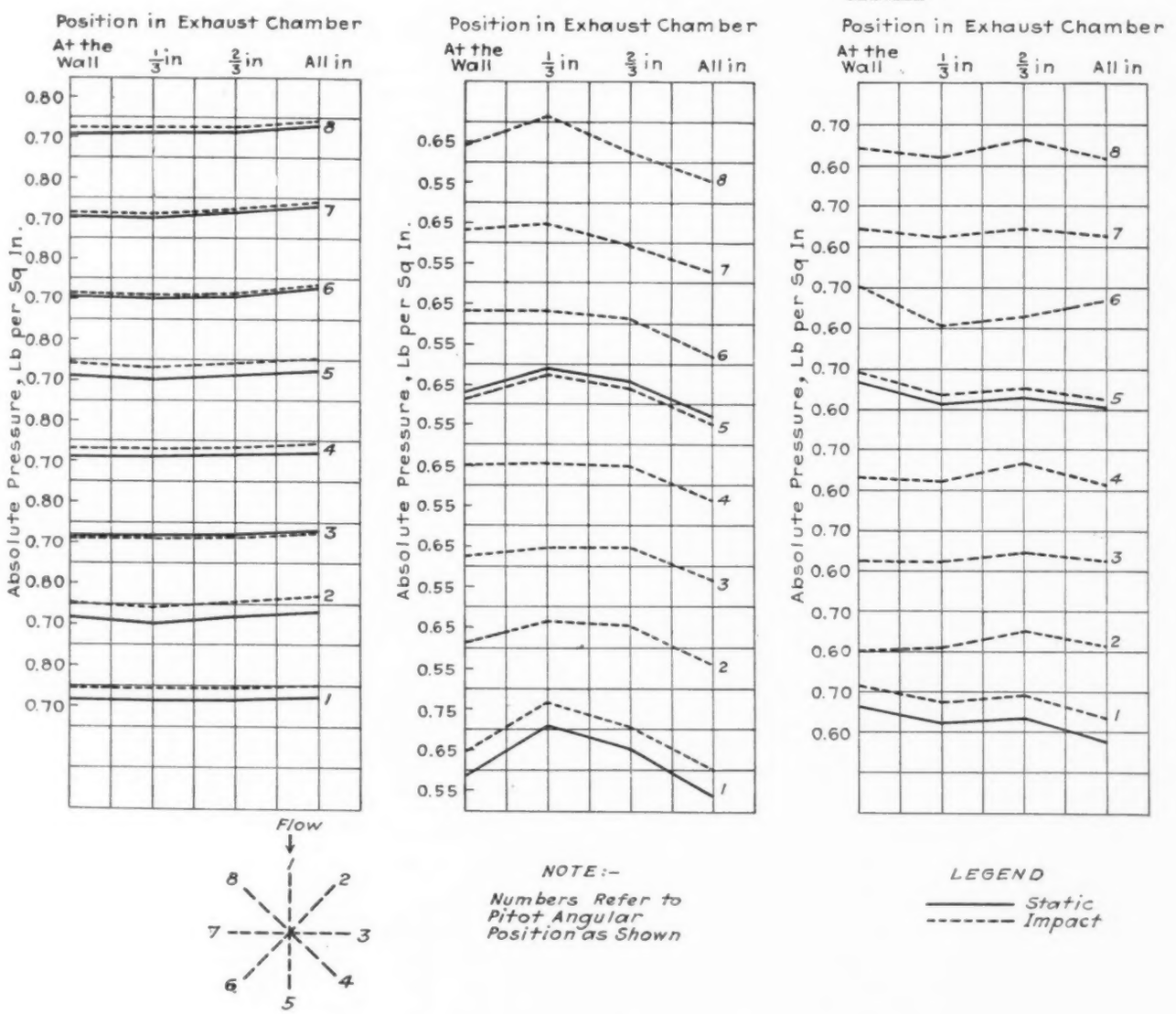


FIG. 5 DETAIL OF PITOT-TUBE HEAD USED IN EXHAUST CHAMBER



FIGS. 2, 3, AND 4 IMPACT- AND STATIC-PRESSURE READINGS IN TURBINE EXHAUST

TABLE 1

Test no.		Angular position of pitot							
		1	2	3	4	5	6	7	8
	Static	28.54	28.53	28.53	28.54	28.55	28.55	28.55	28.54
	Impact	28.49	28.50	28.53	28.52	28.51	28.55	28.54	28.52
(1)	Observed diff., in. hg	0.05	0.03	0.00	0.02	0.04	0.00	0.01	0.02
	Corrd. diff., in. hg	0.06	0.07	0.01	0.04	0.06	0.01	0.02	0.03
	Corrd. diff., per sq in.	0.030	0.035	0.005	0.020	0.030	0.005	0.010	0.015
	Static	28.70	...	...	...	28.70	...	...	...
	Impact	28.62	28.74	28.72	28.71	28.67	28.67	28.70	28.70
(2)	Observed diff., in. hg	0.08	...	...	...	0.03	...	...	...
	Corrd. diff., in. hg	0.11	...	...	...	0.04	...	...	...
	Corrd. diff., per sq. in.	0.054	...	...	...	0.020	...	...	...
	Static	28.72	...	...	...	28.74	...	...	...
	Impact	28.62	28.75	28.74	28.72	28.74	28.78	28.78	28.71
(3)	Observed diff., in. hg	0.10	...	...	...	0.00	...	...	...
	Corrd. diff., in. hg	0.12	...	...	...	0.03	...	...	...
	Corrd. diff., per sq in.	0.059	...	...	...	0.015	...	...	...

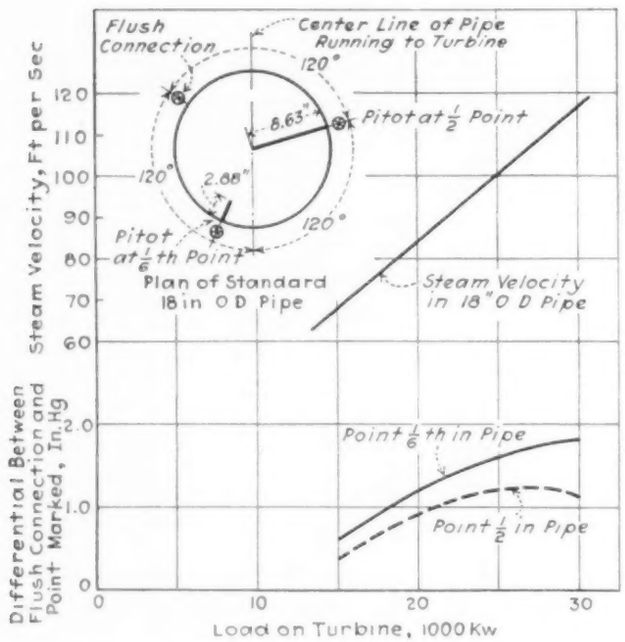


FIG. 6 IMPACT- AND STATIC-PRESSURE READINGS IN STEAM-SUPPLY PIPE

The velocity of the steam in each test, respectively, 227, 250, and 256 ft per sec, does not account for the changes in the characteristics of the impact values.

Fig. 6 shows the relation between the impact pressures at two points on a section of an elbow in a turbine steam-supply line and the static pressure at one point on the wall of the elbow. The variation in impact pressures indicates that no simple relation between impact and static pressure exists and extensive traversing might be necessary to establish the mean impact pressure. It is true that other corrections having little significance on results are observed in steam-turbine testing but in such cases there is no substantial cost or unusual operating inconvenience involved.

Therefore, while I am thoroughly in favor of further investigations on a smaller unit along proposed lines, I believe it would be rash to adopt this method as standard procedure without the factual evidence which might demonstrate the effect upon results.

AUTHOR'S CLOSURE

C. HAROLD BERRY.[10] Since the paper was written expressly to stimulate discussion, it has been highly gratifying that so many have so ably commented. That they are virtually unanimous in their opinions of the several suggestions put forth in the paper is equally gratifying to the author, since the comments largely agree with his own opinions, which differ from the statements given in the paper, as implied in its opening paragraph. Apparently the consensus of opinion is that

(1) We should continue to define the ideal engine as heretofore, in terms of static pressures

(2) That it would be proper to charge against the turbine the kinetic energy of the steam coming to it

(3) That it is not desirable to credit the turbine with the kinetic energy of the exhaust steam

(4) That the measurement of impact pressures in the present state of the art is a matter of considerable difficulty.

The experimental results reported by Mr. Grob are of high value, since the questions at issue cannot be settled by speculation. It is to be hoped that he and others will from time to time make trial of the impact tube and thereby develop a body of experience upon which sound opinions can be based. One admits at the outset that there seem to be difficulties in the way.

It is perhaps proper to mention again that there are two distinct questions involved: (1) Should kinetic energy be considered? (2) Does the impact tube provide a more convenient means of measuring pressures than the static connection?

Clearly, if it is desirable to compute kinetic energies, it can be done on the basis of any adequate system of measurements; indeed it has been done regularly for years past, in working up the exhaust loss of the steam turbine. The consideration of kinetic energy is not dependent upon the use of an impact tube.

On behalf of the A.S.M.E. Power Test Codes Individual Committee No. 6 (Steam Turbines), the author wishes to thank those who have discussed the paper for their cooperation in clarifying and crystallizing opinion on these aspects of its task.

[10] Professor of Mechanical Engineering, Harvard University, Cambridge, Mass. Mem. A.S.M.E.

Hydrostatic Boundary Forces

TO THE EDITOR:

Since publication of my paper[11] a written communication from Professor Baumgart, of Leningrad, has been received in which he refers to a similar paper in Russian on the same subject by S. G. Gutman[12] which was published in 1934, in the "Transactions of the Scientific Research Institute of Hydrotechnics," Vol. 11, Leningrad, U.S.S.R., entitle "Weight of Elastic Body Expressed as External Hydrostatic Load."

In this paper, the analogy between the stress condition in an elastic body resting under gravity forces applied to the mass of the body, and the condition when that body is immersed in a liquid, was demonstrated for the general three-dimensional case containing as a special case the two-dimensional one.

[11] "Distributed Gravity and Temperature Loading in Two-Dimensional Elasticity Replaced by Boundary Pressures and Dislocations," by M. A. Biot, *Journal of Applied Mechanics*, Trans. A.S.M.E., vol. 57, 1935, p. A-41.

[12] Research Engineer, Scientific Research Institute of Hydrotechnics, Leningrad.

When applying the deduced analogy to model studies of stresses, it was necessary to take into consideration the weight of the model.

It was further noted that in using this analogy for the analysis of girders, special attention must be paid to the statical determinateness of the girder supports.

It was shown in my paper[1] that in two-dimensional elasticity a system of body forces derived from a harmonic potential V ($\Delta V = 0$) can be properly replaced by hydrostatic boundary forces. This is applied to gravity and temperature stresses.

In his proof Dr. Gutman does not mention multiconnected bodies. If the body contains a hole or a channel in such a way that it becomes multiconnected we must also prove that the hydrostatic stress does not produce dislocation. The proof of this can be made exactly as in the two-dimensional problem by projecting all displacements on a vertical plane.

The stresses arising from Dr. Gutman's considerations may be considered as resulting from two systems of external loading:

(1) By immersion of the whole system in a liquid of the same specific weight as that of the elastic body.

(2) By assuming the body to be devoid of weight, and by loading its surface by a hydrostatic loading equal and opposite to that of 1.

The negative hydrostatic pressures of system 2 can always be made positive by adding a uniform pressure to system 2 and subtracting the same pressure from system 1.

M. A. BIOT.[13]

[13] University of Louvain, Belgium.

A.S.M.E. BOILER CODE

Proposed Revision of A.S.M.E. Code for Unfired Pressure Vessels

THE A.S.M.E. Boiler Code Committee contemplates a complete revision of Section VIII of the A.S.M.E. Boiler Construction Code which covers construction of unfired pressure vessels.

The Special Committee appointed for this purpose desires to obtain criticisms and suggestions on the following numbered items. The proposed revision scheme and the details have been tentatively agreed upon by the special committee except for the factor of safety, the stress-relieving requirements, and the limitations. The use of a factor of safety of $4\frac{1}{2}$ instead of 5, as in the present A.S.M.E. Unfired Pressure Vessel Code (item 8), the stress-relieving requirements (item 10), and the limitations (items 13, 14, and 15) in the proposals given below have not been agreed upon by the special committee. It is anxious to obtain as many criticisms and suggestions as possible on these points in particular. Communications should be sent to the secretary, Boiler Code Committee, 29 West 39th Street, New York, N. Y.

Proposed Revision Plan.

(1) That the revised Unfired Pressure Vessel Code be divided into two parts tentatively designated as Parts 1 and 2.

(2) That Part 1 comprise the present Section VIII revised so that it will follow the same general arrangement as the API-ASME Code for Unfired Pressure Vessels and also in certain other details, the allowable working stresses to be made less than in Part 2. Separate rules will be given in Part 1 for fusion-welded vessels now covered by Par. U-70, following in general the present rules of the A.S.M.E. Code.

(3) That Part 2 embody the additional requirements, such as a mandatory inspection section, which justify a factor of safety of 4, and that the requirements of Part 2 be made identical with those of the API-ASME Code.

Proposed Revisions Applicable to Fusion Welding Under Part 1.

(4) That reference to Pars. U-68, U-69, and U-70 be eliminated. For purposes of discussion and offering comments on the revisions, the types of vessels covered by these paragraphs are tentatively referred to in what follows as *A*, *B*, and *C*.

(5) That in the beginning of the revised code a statement be included outlining the limitations of the different types of vessels, if any; namely, what vessels must be both X-rayed and stress relieved.

(6) That vessels be required to be stamped with the pressure and temperature limitations, and when stress relieved and radiographed with the letters "SR" and "XR," respectively.

That the requirements in the following numbered paragraphs of the API-ASME Code be incorporated in proposed Part 1, except as indicated.

(7) *Par. W-201.* Omit part which states that when the vessel is to be stress relieved after welding, the test coupon before testing shall be stress relieved, etc.

(8) *Par. W-309.* Change caption for "*s*" to make it read:

s = maximum allowable unit working stress from Table --- for *A* and *B* vessels (the stresses in the table to correspond to a factor of safety of $4\frac{1}{2}$). The value of "*s*" for *B* vessels in which the shell thickness is $\frac{5}{8}$ in. or less, shall not exceed 11,000 lb per sq in., irrespective of the strength of the material.

(9) *Par. W-313.* Omit first paragraph bearing on location of openings in heads.

(10) *Par. W-318.* Revise the rule which bears on stress relieving of fusion-welded vessels when constructed of other than steel complying with A.S.T.M. Specifications A-149 and A-150 to make it read:

"Vessels shall be stress relieved when the ratio of the inside diameter to the cube of the shell thickness in inches at any welded joint of the shell or head plate is less than *R*,
Where:

R = 100 for shell diameters of 50 in. or less,
R = 150 — *D* for shell diameters of 50 in. to 100 in., where *D* = shell diameter in in.,
R = 50 for shell diameters of 100 in. and over."

Retain the present requirement of the API-ASME code that vessels shall be stress relieved when the plates are over $1\frac{1}{4}$ in. in thickness at any welded joint.

(11) *Par. W-329.* Modify to allow the 2-in. deduction in diameter as in the A.S.M.E. Code rules.

(12) *Par. W-521.* Make the requirements for bend tests read:

". . . shall be at least 30 per cent for *A* vessels; for *B* vessels the elongation shall be at least 30 per cent for stress-relieved welds, and 20 per cent for unstress-relieved welds. For *C* vessels the elongation shall be at least 10 per cent."

Proposed Limitations for the Different Types of Vessels.

(13) Fusion-welded *A* vessels shall be both radiographed and stress relieved. These vessels may be used for any purpose when constructed in accordance with the rules in this Code.

(14) Fusion-welded *B* vessels need not be radiographed. They shall be limited to a maximum thickness of $1\frac{1}{2}$ in. and shall not be operated at pressures in excess of 400 lb per sq in., except that in the case of vessels operated under hydraulic pressure at atmospheric temperature, the pressure limitation shall not apply.

These vessels may be used for any purpose except for containing:

(1) Lethal liquids or gases.

(2) Other liquids at temperatures above 350 F.

(3) Other gases at temperatures above 700 F.

(15) Fusion-welded *C* vessels when constructed in accordance with the rules in the Code may be used for the storage of gases or liquids, except lethal gases or liquids, at temperatures not materially exceeding their boiling temperature at atmospheric pressure and at pressures not to exceed 200 lb per sq in., and/or not to exceed a temperature of 250 F. Plate thickness shall not exceed $\frac{5}{8}$ in.

THIS MONTH'S AUTHORS

TO MOST engineers coulomb is an electrical unit written with a lower-case initial. The vague impression that a Coulomb lived and made his contributions to electricity when it was an academic and scientific curiosity will be generally admitted. But the vital personality of the French scientist, and his important and fundamental work in mechanics are too little known. These Professor Hollister has reconstructed in the leading article of this issue.

S. C. HOLLISTER, associate dean of engineering and director of the School of Civil Engineering at Cornell University, is a member of The American Society of Mechanical Engineers and an enthusiastic supporter of the Society's Division of Applied Mechanics. Readers of MECHANICAL ENGINEERING will recall the brilliant work he did in connection with the joints of the penstocks for Boulder Dam, reported in our issue of August, 1934. With his teaching and administrative duties, for which he was prepared by active engineering practice, particularly in the fields of concrete construction and welding, Professor Hollister finds time to devote his scholarly talents to a study of engineering history and of original scientific and engineering documents.

ROBERT J. MOORE, industrial and engineering chemist, and development manager of the varnish-resin division of the Bakelite Corporation, carried on graduate studies in chemistry and chemical engineering at Columbia University. From 1924 to 1930 he was research chemist with Pratt & Lambert, Inc., Buffalo, N. Y., paint and varnish manufacturers. He has been secretary and chairman of the Paint and Varnish Division of the American Chemical Society, and since 1932 chairman of the technical committee of the New York Paint and Varnish Club. He is active in the committee work of numerous technical societies.

BORIS A. BAKHMETEFF, engineer, statesman, teacher, and member of The American Society of Mechanical Engineers, was born in 1880 at Tiflis, Caucasus, Russia, and was graduated in 1898 from the Classical Gymnasium, Tiflis, and from the Institute of Engineers of Ways of Communication, St. Petersburg, in 1903. From 1904 to 1905 he was engaged in research work at the Polytechnic Institute, Zurich, Switzerland, and in practical work in the United States (New York State Barge Canal and office of Colonel Bogart, consulting engineer). In 1911 he received the degree of "Adjunct Applied Mechanics," corresponding to Doctor of Engineering. He performed academic work at the Polytechnic Institute of the Emperor Peter the Great, St. Petersburg, and from 1905 to 1916, was assistant professor, docent, and professor; author of many lectures; and consulting engineer in St. Petersburg, specializing on water power. He was connected with the Dneiper project (300,000–1,000,000 hp) as chief engineer; the Volchow and Immatra plants (150,000 hp) of the Petrograd Company for Transmission of Hydraulic Power as chief engineer; and the Rion Plant, Caucasus (50,000 hp), for the electrification of the Trans-Caucasus Railroad; a member of the Technical Board of the Russian Reclamation Service; chairman of the Board for Engineering Research of the Reclamation Service; expert on governmental and municipal boards connected with irrigation, internal navigation, sewage disposal, legislation on public utilities, and water rights. With the advent of the World War he volunteered first with the Red Cross, subsequently with the Central War Industrial Committee, a public voluntary organization of business and professional men. In 1915–1916, he was chief plenipotentiary of the C.W.I. committee to the United States and a member of the Anglo-Russian Purchasing Commission. In March, 1917, after the fall of the Czarist government, he was appointed Under Secretary of State (vice-minister) for Commerce and Industry of the Provisional (Kerensky) Government and in May, 1917, Ambassador to the United States, remaining in that post until 1922, at which time he resigned. Since 1923 he has been established in New York as consulting engineer connected with various industrial enterprises.

WALTER RAUTENSTRAUCH, professor of industrial engineering at Columbia University, and chairman of the Finance Committee of The American Society of Mechanical Engineers, is well known as a frequent contributor to MECHANICAL ENGINEERING on matters relating to economics and industrial management, and as pioneer in the use of the so-called "break-even" chart for analyzing industrial economic performance. A graduate of the University of Missouri, he taught at the University of Maine and at Cornell University before joining the Columbia faculty in 1906. His forceful lectures and articles have always reflected the application of rational engineering methods to social and economic problems.

Members of The American Society of Mechanical Engineers and particularly of its Oil and Gas Power Division, know F. G. HECHLER best as the courteous and able administrator of the national meetings of the Division held at Pennsylvania State College; where he is professor of engineering research and assistant director of the engineering experiment station. From the time he received the degree of M.E. from the University of Missouri in 1910, to the present, Professor Hechler has, with the exception of three years spent as general manager of the Vibration Specialty Company, of Philadelphia, 1919 to 1922, been engaged in teaching and research at Rensselaer, U. S. Naval Experiment Station, Annapolis, and Pennsylvania State College. He has written many papers and bulletins on heat transmission, dynamic balancing, and thermodynamics. He is a member of The American Society of Mechanical Engineers and of the Committee on Heat Transfer of the National Research Council.

WILLIAM D. ENNIS, consulting engineer, economist, teacher, and Treasurer of The American Society of Mechanical Engineers, returned in 1928 as Alexander Crombie Humphries professor of economics of engineering, to Stevens Institute of Technology from which he was graduated in 1897. His engineering career has embraced professional and industrial practice, and has included professorships at The Polytechnic Institute of Brooklyn, Columbia University, and the United States Naval Academy. He is the author of a book on thermodynamics, and industrial management, fields in which he taught for many years, and numerous other subjects. He has given much study to the financial and economic aspects of engineering and has practiced widely in this field. His recent contributions to MECHANICAL ENGINEERING have dealt with this subject.

L. E. KUNKLER who is the author of the article on "The Spraying of Molten Metal," is president of the Metallizing Company of America, Los Angeles, Calif. After a high-school education he joined the Army and was assigned to the Rainbow Division. At the close of the War he entered the hardwood lumber business, both retail and manufacturing, working for his father. In 1931 Mr. Kunkler became connected with the Metallizing Company of Los Angeles, Ltd., as sales manager. The following year the Metallizing Company of America was incorporated and he was elected president.

MAX JAKOB is a name familiar to students of thermodynamics for the past quarter century in connection with investigations in the thermal and physical properties of steam. His recent lecture tour, covering this country from coast to coast, afforded those to whom the name had long been more legendary than real an opportunity of discovering a kindly and able scientist, with a brilliant intellect and a keen but quiet sense of humor, a passion for intellectual honesty, and a reverence for accuracy and research. Returning to Germany, Doctor Jakob left behind him the manuscript copy of his six lectures, of which the three on evaporation appear in this issue. Until January 1, 1936, Doctor Jakob was connected with the Physicalisch-Technischer Reichstalt, Berlin, Germany. The work which engaged his lifelong activities as a scientist is going forward under the powerful stimulus that only a great scientific intellect can provide. The list of his scientific writings and accomplishments is too long for record in these abbreviated sketches.

Another in the series of reviews of current economic topics of interest to mechanical engineers is "Streamlining the Dismal Science," contributed by JOHN SHUTE, a member of the Department of Economics, Massachusetts Institute of Technology.

REVIEWS OF BOOKS

And Notes on Books Received in the Engineering Societies Library

Engineering Valuation

"Engineering Valuation," by Anson Marston and Thomas R. Agg. McGraw-Hill Book Company, Inc., New York, 1936. Cloth, 6 × 9 in., 655 pp., $6.

Reviewed by Earl B. Smith[1]

THIS is truly a treatise on the basic principles of engineering valuation of industrial properties. It is perhaps more inclusive and thorough than other books on the subject. The text has been in the process of development since about 1920. It passed through five mimeographed editions and was thoroughly tried out as a textbook. The authors are, respectively, the senior dean and the dean of engineering at Iowa State College.

Engineering valuation (or appraisal), "is the art of estimating the fair exchange worth of specific properties in cases where professional engineering knowledge and judgment are essential." This definition on the first page indicates the scope of the book to be rather wide, since it thoroughly defines all factors affecting the determination of worths, and gives in detail the methods used, examples of application, and the legal aspects. There are 68 important court decisions briefly discussed, showing how, in addition to the technical consideration and methods of valuation, the engineer must be guided by the legal effects and in turn the legal aspects are dependent upon the engineer's methods and judgment. These court cases show the increasing difficulties that the valuation engineer has had to meet in order to get fair valuations safely through the courts.

As a textbook some would prefer to rearrange the order of the material, but as presented it is divided into three main parts. Part 1 includes valuation; value; industrial property; accountancy; mortality characteristics; and depreciation, which is treated thoroughly. The different principles of depreciation and their relative importance are presented with the methods for their determination. The use and application of the theoretical, actual, and wise-retirement principles are discussed. The new "wise-retirement formula" which is presented gives the rather positive answer as to whether the depreciation values warrant retirement.

Part 2 presents more fully the fundamental engineering principles of valuation, and the various specialized methods which have been developed for the practice of engineering valuation. This section shows the importance of the effect of wages, prices, indexes, organization structures, intangible, and good-will values. In this section the court cases are fully discussed from an engineering standpoint and are classified into seven historical periods beginning with 1830.

Part 3 gives the valuation of different factors and actual examples of the valuation of some public-utility properties.

The practical engineering phases of this book are excellent and should make it of value as a textbook and reference book. The sections on statistical methods present some unusual methods which will be found of considerable interest and value in determining present worth, probable life, and expectancy. However, some few theoretical points should be further mentioned.

Certain theories have been deduced from experience with valuation problems and statistical evidences of the life of physical property; some of these presentations will be questioned by the critical reader. In the section on the theory of mortality-frequency curves (pp. 57–62), it is unfortunate that the authors have introduced a new notation for the De Moivre (or Gaussian) normal curve, which they have not named as such. The general equation for the Pearsonian frequency has an altogether different physical meaning in the form presented than as given originally by Pearson; the differential form should be written as

$$\frac{1}{y}\frac{dy}{dx} = \frac{\text{a function of } x}{\text{another function of } x}$$

which is either a simple or higher hypergeometrical function (Philo. Trans., A, vol. 216, 1916, pp. 429–57). The authors further state that none of the Pearsonian curves fit the skewed mortality data and in lieu of which "Winfrey developed new type frequency equations." In fact these equations are nothing more than variations of Pearson's curves. A proper mathematical statistical analysis would show that any of these mortality functions could be fitted very simply by incomplete-gamma or -beta functions (*Biometrica*, vol. 25, pp. 379–410). Their equation for "the probable-life curve" is obviously in error; the parabolic equation, $y = ax^b$, gives the age x as a logarithmic function. Time is always linear and is given by the geometric equation of $y = ab^x$.

In the section on indexes the authors suggest the desirability of "correct interpretation," but never mention tests on the validity of their indexes; no mention is made of Cauchy's inequality test, or time and factor-reversal tests for index numbers which is an easy and valuable test.

The sinking-fund method of depreciation, which is favored by these authors, places a heavy burden on the company during the latter stages of the life of the physical property; it makes the probability of being caught with unamortized obsolescent equipment much higher than other acceptable methods; it gives the consumer lower utility rates in the earlier stages of production at the expense of the producer. It can be shown that the value of a machine and that of a unit of its output are interrelated, each affecting the other. This economic truism must underlie a correct theory of depreciation. Depreciation cannot, as has been proposed, be charged as a function of output alone; the omnipresence of interest prevents it. Such a depreciation-function curve as is here suggested is concave upward rather than downward as in the case of the sinking-fund method.

Notwithstanding the foregoing comments, on some theoretical points, the practical methods of Marston and Agg have been accepted as precedent by the court. It will be of considerable value to the practicing engineer and for educational purposes. The authors have made a worth-while contribution toward the cause of engineering valuation and increased industrial efficiency through the determination of the proper values entering into the cost of industrial enterprises.

[1] Professor of Mechanical Engineering, College of the City of New York, New York, N. Y. Mem. A.S.M.E.

Transportation

PRINCIPLES OF INLAND TRANSPORTATION. By Stuart Daggett. Harper and Brothers, New York, N. Y., 1934. Cloth, $6\frac{1}{2} \times 9\frac{1}{2}$ in., 898 pp., $4.

ECONOMICS OF TRANSPORTATION. By D. Philip Locklin. Business Publications, Inc., Chicago, Ill., 1935. Cloth, $6\frac{1}{2} \times 9\frac{1}{2}$ in., 788 pp., $4.

REVIEWED BY E. DILLON SMITH[2]

THESE books are studies of the economic aspects of transportation. They are concerned not only with the internal economic characteristics of the industry but also with the broader relationships between the transport industry and the present industrial society. Because of this relation and emphasis, the engineer will find that these two books treat a problem of "profitable" interest; profitable in that costs of transporting natural resources and other materials is often a large element in the production costs of any enterprise. So it is with the distribution of these produced goods when they are in competition with goods of producers in any specialized industrial economy.

Dr. Stuart Daggett, professor of railway economics, University of California, describes all major forms of inland transportation—railroad, inland waterway, highway and motor trucks, street and interurban railways, and air transportation—with the effects of improved transportation upon industrial society. Certainly this book brings out the fact that "the different mechanisms of transport are so closely connected with one another in the common task of moving people and goods, that it no longer is possible to understand the activities of any one of them without being cognizant in some degree of the work of the others also. Nor is it even true that the underlying principles of transport still find their best expression in the field of a single agency."

First, some will feel that the historical aspects of the problem are given too much space. Second, a treatment of coastwise and intercoastal steamship transportation and pipe-line transportation for petroleum and natural gas would have improved the work and the discussion of airway, highway, and electric transport might have been expanded. But certainly this is a fine and constructive piece of writing.

Dr. D. Philip Locklin, assistant professor of economics, University of Illinois, is concerned primarily with railroad transportation; only about 18 per cent of the book deals with water, highway, and air transportation. By choice, there is no description of the transportation facilities and services, and passenger transportation.

Professor Locklin makes a valuable contribution to transportation economics when dealing with the relation of freight rates to prices of raw materials and finished goods, and to the location of industries. Numerous figures aptly illustrate and explain the presentation, although mechanically the cuts are not all that could be desired. There is, however, no question as to the value of this book.

These volumes represent impressive contributions in this field, and will unquestionably aid all those who, realizing the importance of modern transportation, are devoting their efforts to improving the efficiency of the industrial enterprise.

[2] Chairman, A.S.M.E. Committee on Statistics in Industry; member, Economics Committee, Economics and Industrial Administration, Pratt Institute, Brooklyn, N. Y.

Books Received in Library

AIRPLANE AND ITS ENGINE. By C. H. Chatfield, C. F. Taylor, and S. Ober. Third edition. McGraw-Hill Book Co., New York and London, 1936. Cloth, 6 × 8 in., 401 pp., illus., diagrams, charts, tables, $3. This book is intended "for the reader who desires a sound knowledge of the basic principles and a broad view of the present development of the airplane and its power plant, without giving to the subject the intensive study which is essential for the designing engineer or the expert mechanic." The new edition has been carefully revised and the material it contains has been brought up to date.

ALLOYS OF IRON AND CARBON. Vol. 1. Constitution. (Alloys of Iron Research, Monograph Series.) By S. Epstein. Published for the Engineering Foundation by the McGraw-Hill Book Co., New York and London, 1936. Cloth, 6 × 9 in., 476 pp., illus., diagrams, charts, tables, $5. This, the sixth of the series of monographs on the alloys of iron, is the first portion of a critical summary of our knowledge of the iron-carbon alloys. It discusses their constitution and heat-treatment, including the correlation of data on the iron-cementite and iron-graphite diagrams, the structure of these alloys after various treatments, the constitutional changes caused by thermal or other treatments and the effect of various factors on these changes. An extensive bibliography is appended.

AUFSCHAUKELUNG UND DÄMPFUNG VON SCHWINGUNGEN. Vol. 2. zu Grundzüge der Technischen Schwingungslehre. By O. Föppl. J. Springer, Berlin, 1936. Cloth, 6 × 8 in., 121 pp., illus., diagrams, charts, tables, 8.40 rm. In this book, which forms volume two of his "Grundlagen der technischen Schwingungslehre," Dr. Föppl discusses a number of questions which have acquired technical importance in recent years. The balancing of crankshafts, the artificial damping of vibrations, the prevention of resonance, and the vibration of ships are discussed, as well as other questions.

AUTOMOBILE VALVE REPAIR AND BENCH WORK. By C. R. Strouse and R. O. Olden. International Textbook Co., Scranton, Pa., 1935. Leather, 5 × 8 in., illus., diagrams, charts, tables, $1.85. A manual for the automobile mechanic, which gives clear directions for repairing and adjusting valves and for the various operations carried out at the bench, such as chipping, filing, keyseating, reaming, and thread cutting.

BERECHNUNGSVERFAHREN ZUR BESTIMMUNG DER KRITISCHEN DREHZAHLEN VON GERADEN WELLEN. By J. J. Holba. Julius Springer, Vienna, 1936. Cloth, 6 × 9 in., 190 pp., illus., diagrams, charts, tables, 18.60 rm. This book provides machine designers with a comprehensive discussion of methods for calculating the critical speeds of rotating shafts. The widely scattered literature is reviewed quite thoroughly, the methods used for various conditions of loading are presented, and examples of their use given.

CORROSION RESISTANCE OF METALS AND ALLOYS. (American Chemical Society Monograph No. 71.) By R. J. McKay and R. Worthington. Reinhold Publishing Corporation, New York, 1936. Cloth, 6 × 9 in., 492 pp., illus., diagrams, charts, tables, $7. A general survey of the subject, in which the results of recent studies are summarized under one plan. Part one gives a concise outline of the theory of corrosion. Part two summarizes the useful published data on the corrosion of the various metals and alloys, with critical interpretations. Select bibliographies accompany each chapter. The book will be useful to all who work with metals.

DEVELOPMENT OF THE PARSONS STEAM TURBINE. Part 1, Turbo-generating Machinery; Part 2, Industrial Turbo-Machinery. By R. H. Parsons. Constable and Co., London, 1936. Cloth, 9 × 12 in., 420 pp., illus., diagrams, charts, tables, 42 s. During 1934 and 1935 a detailed, authoritative account of the development of Parsons turbine machinery appeared in two series of articles in *The Engineer*. These articles are republished in this handsome volume, which hold much of interest for the historian and turbine builder. The first part of the story traces the development of the turbine and the high-speed electric generator during fifty years; the second gives an account of the application of the turbine to pumps, fans, blowers, and compressors. Outstanding machines of their day are described in chronological order, with full accounts of the details of their construction. The book is profusely illusrrated with drawings and photographs.

DIESELMASCHINEN VI. Sonderheft V.D.I. (Verein deutscher Ingenieure.) V.D.I. Verlag, Berlin, 1936. Paper, 8 × 12 in., 151 pp., illus., diagrams, charts, tables, 6 rm. This special number brings together the more important papers on Diesel engines which have appeared during recent years in the *V.D.I. Zeitschrift* and "*Forschung auf dem Gebiete des Ingenieurwesens.*" The book affords a useful review of the most important problems in this field.

DRILLING AND SURFACING PRACTICE. By F. H. Colvin and F. A. Stanley. McGraw-Hill Book Co., New York and London, 1936. Cloth, 6 × 9 in., 431 pp., illus., diagrams, charts, tables, $4. A description of methods of drilling, reaming, tapping, planing, shaping, slotting, milling, and broaching now in

use. Attention is concentrated upon modern developments in these operations and the best practice of today.

FLOUR MILLING PROCESSES. By J. H. Scott. D. Van Nostrand Co., New York, 1936. Cloth, 6 × 9 in., 416 pp., illus., diagrams, charts, tables, $7.50. This volume embodies the conclusions of an experienced miller upon various important operations of flour milling. The cleaning and conditioning of wheat, the processes of grinding, dressing, and extracting flour, the effects of moisture, and other matters are discussed. The book is based largely upon personal experiments in British mills.

FORSCHUNGSHEFT 378. GRUNDGESETZE DER ZERKLEINERUNG, by F. Hönig. V.D.I. Verlag, Berlin, 1936. Paper, 8 × 12 in., 21 pp., charts, diagrams, tables, 5 rm. This report gives the results of investigations undertaken with the object of clarifying the controversy between Rittinger and Kick concerning the law of crushing and pulverizing.

Forschungsheft 379. WÄRMEÜBERGANG BEI FREIER STRÖMUNG AM WAAGERECHTEN ZYLINDER IN ZWEI-ATOMIGEN GASEN. By R. Hermann. V.D.I. Verlag, Berlin, 1936. Paper, 6 × 12 in., 24 pp., illus., diagrams, charts, tables, 5 rm. A theoretical and experimental investigation of the free convection of heat from horizontal cylinders in diatomic gases.

FOUNDRY WORK. By R. E. Wendt. Third edition. McGraw-Hill Book Co., New York and London, 1936. Cloth, 6 × 9 in., 240 pp., illus., diagrams, tables, $2. This is a practical textbook on molding, dry-sand coremaking, melting and mixing metals, and problems in foundry management, intended for use in schools and colleges and by apprentices in commercial shops. This new edition includes recent developments in castings manufacture, such as mass-production foundries, alloy iron and steel castings, standard pattern colors, and correct design of castings.

FRONTIERS OF SCIENCE. By C. T. Chase. D. Van Nostrand Co., New York, 1936. Cloth, 6 × 9 in., 352 pp., illus., $3.75. The purpose of this book is to "visit each of the present frontiers of science, to see what is being done there, and to make inquiry as to the possible effect of this work on human destiny and on man's idea of his place in a universe which at times appears to be so vast and so incomprehensible as to render the human race a thing of supreme insignificance." Dr. Chase reviews progress in astronomy and astrophysics, atomic physics and physical chemistry, organic chemistry, biochemistry, and health.

HEAT for Advanced Students. By the late E. Edser. Revised edition by N. M. Bligh. The Macmillan Co., London and New York, 1936. Cloth, 5 × 7 in., 487 pp., illus., diagrams, charts, tables, $1.75. The popularity of this text, published first in 1899, is attested by the fact that it has been reprinted twenty times. The revised edition now issued by N. M. Bligh, retains the essential character of the work, but obsolete matter has been replaced by up-to-date theoretical and experimental treatment and the whole text thoroughly modernized. The book is intended to provide a comprehensive account of the theoretical and experimental aspects of the subject, so far as this can be done without the use of higher mathematics.

HEIZUNG UND LÜFTUNG. Vol. 2. (Sammlung Göschen 343.) By J. Körting and W. Körting. Walter de Gruyter & Co., Berlin and Leipzig, 1936. Cloth, 126 pp., illus., diagrams, charts, tables, 1.62 rm. The first volume of the sixth edition of this textbook having discussed the general principles, this volume is devoted to the design and construction of heating and ventilating installations. Heating by stoves, hot air, hot water and steam, and ventilation and air conditioning are discussed concisely, clearly, and practically.

HOW TO USE PSYCHOLOGY IN BUSINESS. By D. A. Laird. McGraw-Hill Book Co., New York and London, 1936. Cloth, 6 × 10 in., 378 pp., illus., diagrams, charts, tables, $4. This is a thoroughly practical book on industrial psychology, written for the average business man. In everyday language, it discusses a wide variety of problems of personality and suggests methods for handling many situations that arise in business activities. The illustrations add to the value of the book, which contains much sound information.

INHALTSVERZEICHNIS DER ZEITSCHRIFT DES VEREINES DEUTSCHER INGENIEURE, 1931–1935, Band 75–79. V.D.I. Verlag, Berlin, 1936. Paper, 8 × 12 in., 138 pp., 8 rm. (6 rm. in U.S.A.) This volume contains author and subject indexes to volumes 75–79 (1931–1935) of the *Zeitschrift*. The work is carefully done and greatly facilitates reference to the periodical.

MAINTENANCE OF HIGH SPEED DIESEL ENGINES, a practical handbook for Diesel Engine Fleet Owners, Maintenance Engineers, Operators, Drivers, and Mechanics. By A. W. Judge. D. Van Nostrand Co., New York, 1936. Cloth, 5 × 9 in., 192 pp., illus., diagrams, charts, tables, $3.50. The object of this book is to provide practical information on the operation and maintenance of small high-speed oil engines. A knowledge of gasoline-engine practice is assumed and the present volume is devoted to the special requirements of the Diesel engine. Engine adjustments, troubles and remedies, fuel pumps and injectors, starting and slow running, fault location and cure, and other topics are discussed.

MANUAL OF PHOTO-ELASTICITY FOR ENGINEERS. By L. N. G. Filon. University Press, Cambridge, England; Macmillan Co., New York, 1936. Cloth, 5 × 8 in., 140 pp., illus., diagrams, charts, $1.50. The aim of this book is to give "a practical investigator who wishes to use photoelastic methods in order to explore the stress-distributions occurring in any problem in which he is interested, a brief account sufficiently complete and explicit to enable him to set up his apparatus and to use it in the best possible manner."

MAX EYTH zum hundersten Geburtstag, by C. Matschoss. LANDWIRTSCHAFTSTECHNIK IN DEUTSCHLAND, by W. Stauss. Deutsches Museum, Abhandlungen und Berichte, jg. 8, heft 2. V.D.I. Verlag, Berlin, 1936. Paper, 6 × 8 in., 63 pp., illus., 0.90 rm. This booklet is issued to commemorate the centenary of the birth of Max Eyth, the engineer poet and pioneer in the field of agricultural machinery. Dr. Matschoss gives an interesting sketch of Eyth's life, and Dr. Stauss describes the development of German agriculture during the last hundred years.

TABLES OF PHYSICAL AND CHEMICAL CONSTANTS and Some Mathematical Functions. By G. W. C. Kaye and T. H. Laby. Eighth edition. Longmans, Green & Co., New York, London, Toronto, 1936. Cloth, 6 × 10 in., 162 pp., tables, $4.75. The purpose of this book is to provide a collection of the more reliable and recent determinations of some of the more important constants in a book of convenient size and moderate price. The work was first published in 1911 and the present revision is the eighth. The tables have been brought up to date and errors rectified.

DIE TECHNIK SELBSTTÄTIGER STEUERUNGEN UND ANLAGEN. By G. Meiners. R. Oldenbourg, Munich and Berlin, 1936. Cloth, 7 × 10 in., 225 pp., illus., diagrams, charts, tables, 12.50 rm. An account of modern developments in automatic switchgear and power plants, which describes modern equipment and processes, and their uses for automatic control. These subjects are discussed from a practical point of view. The book affords a good outline of recent practice, presented clearly and concisely.

THEORY OF ELASTIC STABILITY. By S. Timoshenko. McGraw-Hill Book Co., New York and London, 1936. Cloth, 6 × 9 in., 518 pp., illus., diagrams, charts, tables, $6. In recent years, much attention has been given to theoretical and practical investigations of the conditions that govern the stability of such structural elements as bars, plates, and shells. The results of this work, which have appeared in scattered publications in many languages, have been brought together in this book. The author discusses the bending of prismatic bars under simultaneous axial and lateral loads; the buckling of centrally compressed bars, compressed rings, and curved bars; the lateral buckling of beams; and the bending and buckling of thin plates and shells. Particular problems are dealt with and the conditions under which stability must be considered are shown, as well as the methods of solution for each type of problem.

THERMIONIC EMISSION. By T. J. Jones. Methuen & Co., Ltd., London, 1936. Cloth, 4 × 7 in., 108 pp., diagrams, charts, tables, 3 s. This little book aims to give a concise, complete, and up-to-date survey of the fundamental principles of thermionic emission, which will meet the needs of those contemplating experimental research. The book contains a list of standard works and important original papers on the subject.

THERMODYNAMICS, the Principles of Thermodynamics and Their Application to Engineering Processes. By L. C. Lichty. McGraw-Hill Book Co., New York and London, 1936. Cloth, 6 × 9 in., 281 pp., diagrams, charts, tables, $3. In this new text the aim has been to simplify the treatment, strip it of many unnecessary mathematical manipulations, and consolidate it into logical groupings from the viewpoint of thermodynamic analysis rather than mechanical equipment. It also attempts a better balance than is usual between vapor and combustion processes.

V.D.I. (Verein deutscher Ingenieure) Sonderheft SCHWEISSTECHNIK II. V.D.I. Verlag, Berlin, 1936. Paper, 8 × 12 in., 67 pp., illus., diagrams, charts, tables, 4.50 rm. This is the second of a series of volumes in which are collected the important papers upon welding which have appeared in the *Zeitschrift* des Vereines deutscher Ingenieure. Twenty-one papers are included, treating of materials, processes, and testing. The papers give a survey of developments during recent years.

A.S.M.E. NEWS

And Notes on Other Engineering Activities

Welding Practice to Be Discussed by A.S.M.E., Cleveland, Oct. 22-23

Symposium to Be Held During Metal Week

PRESENT practice in the welding of steel and nonferrous metals, and in the design and construction of machinery and structures involving welded joints will be discussed in a group of nine papers that comprise the Welding Practice Symposium, to be held at the Hotel Cleveland, Cleveland, Ohio, October 22–23, during Metal Week. The symposium program has been arranged jointly by the American Welding Society and the Machine Shop Practice, Iron and Steel, Applied Mechanics, Petroleum, and Process Industries Divisions of The American Society of Mechanical Engineers.

Metal Week, which is sponsored by the Metal Congress and Exposition, will also attract to Cleveland for technical meetings the American Institute of Mining and Metallurgical Engineers, the American Society of Metals, and the Wire Association.

The nine technical papers sponsored by the A.S.M.E. and the American Welding Society will appear in the October issue of the Transactions of the Society, copies of which will be in the mail early enough to reach members before the Symposium opens. A program of the four sessions which are scheduled for Thursday and Friday and at which the nine papers will be presented, together with the names of the presiding officers, follows:

Thursday, October 22

9:30 a.m.

Chairman: C. W. Obert
Vice-Chairman: M. Male
Welding Design, by C. H. Jennings
Welding Alloy Steels, by A. B. Kinzel
Arc Welding of Structural Alloy Steels, by W. L. Warner

2:00 p.m.

Chairman: H. F. Henriques
Vice-Chairman: S. M. Weckstein
Rolled Steel in Machine Construction, by H. G. Marsh
Welding Heavy Machinery, by C. A. Wills and F. L. Lindemuth
Discussion of Modern Resistance-Welding Developments of Lighter Products Including Automobiles and Refrigerators, by A. E. Hackett

Friday, October 23

9:30 a.m.

Chairman: A. E. Gibson
Vice-Chairman: Guy Hubbard
Applications of Copper-Alloy Welding, by I. T. Hook
The Electric Welding of Monel and Nickel, by F. G. Flocke and J. G. Schoener
The Welding of Aluminum Alloys, by G. O. Hoglund

2:00 p.m.

Chairman: R. E. W. Harrison
Vice-Chairman: D. M. Gurney
Casting or Welding in Machine Design, by J. L. Brown
Discussion of Radiographic Inspection of Welded Refinery Equipment and Steel-Plate Construction, by H. R. Isenburger
Discussion of the Use of Magnaflux for Inspecting Welds

In order to provide a little advance information on the contents of the papers to be presented, the following brief comments on them have been prepared.

Jennings on Design

The first paper of the Symposium deals with welding design and has been prepared by C. H. Jennings of the Westinghouse Electric & Manufacturing Co. There has been much speculation as to the actual effect of the shrinkage and warpage stresses that are locked up in welded structures after welding, but little has been done to evaluate them or otherwise provide for them in engineering design work. Mr. Jennings has long been an advanced thinker in the stress-analysis field and he has made an exhaustive study of this rather important subject, the results of which are reflected in this paper. His paper should be carefully studied by machine-design experts, as the effects of the localized stresses in welds of the different types have an important bearing upon their fatigue resistance.

Kinzel on Weldability of Alloy Steels

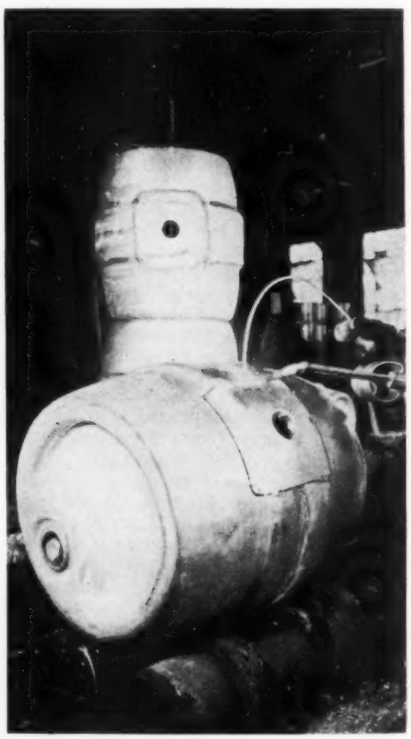
The paper by A. B. Kinzel, Union Carbide and Carbon Research Laboratories, undertakes to bring the reader up to date on the general problem of welding alloy steels. The effects of the different alloying elements upon fusion-welding processes are analyzed and the current tendencies toward the "balanced" alloy steels are outlined. Much important information is offered to the machine designer for use in designing welded structures.

Warner on Alloy Steels

W. L. Warner, of the Watertown Arsenal, in a paper on the welding of alloy steels, offers a preliminary report on an extended series of tests he has under way at Watertown Arsenal to determine the conditions that lead to the best results in welding alloy steels. He has found that the carbon content of the steels has a very important bearing upon their weldability and also that the effect of the different alloying elements is in turn modified by the carbon. He submits actual data on a long series of tests in which many different phases of the effects of the alloys are traced.

Marsh on Rolled Steel in Machine Construction

Opening the second session is a paper by H. G. Marsh, of the Carnegie Steel Co., on



WELDING ALUMINUM BARRELS
(A subject treated in Mr. Hoglund's paper on "The Welding of Aluminum Alloys.")

Rolled Steel in Machine Construction. The author throws out a sharp warning to the management of concerns using welded structures that more thoughtful and careful study should be given to the problem of design for welding. He submits an important message looking toward improvements in designs for welding.

Wills and Lindemuth on Heavy Machinery

From the experience of the Wm. B. Pollock Co., C. A. Wills and F. L. Lindemuth present numerous examples of welding heavy machinery frames and structures.

Nonferrous Metals

Friday's session opens with a group of three papers devoted to the welding of copper alloys, monel metal and pure nickel, and aluminum alloys, presented, respectively, by I. T. Hook, of the American Brass Company, F. G. Flocke and J. G. Schoener, of the International Nickel Company, and G. O. Hoglund of the Aluminum Co. of America. These three papers are comprehensive outlines of modern welding practice in each of their particular fields. Hook's and Hoglund's papers are brief, concise statements of the general status of the art for their particular metals, but Flocke and Schoener have gone into detail with regard to actual welding procedures for welding monel and nickel in some instances. All three papers are important contributions to the art and should be carefully read and understood by machine designers.

Brown on Welding Vs. Casting

At the Friday afternoon session J. L. Brown, of the Westinghouse Electric & Manufacturing Co., will discuss casting vs. welding in machine design. This paper is an excellent analytical statement on this general question of castings versus welded steel for machine frames and structures. The author is connected with a concern that has used both and his paper submits recommendations based on extended experience in which the practicability and economics of the two have been given due consideration.

A.S.M.E. Annual Meeting, New York, Nov. 30 to Dec. 4

Technical Sessions on Many Subjects

PLANS TO improve the quality and member interest in the Annual Meeting of The American Society of Mechanical Engineers, to be held in New York, N. Y., Nov. 30 to Dec. 4, are under way and the technical program is rapidly taking final form.

Technical Sessions to Be Held Monday and Thursday Evenings

As a result of a quickened interest in the problem of presenting a multitude of technical papers on the part of the Committee on Meetings and Program and the Committee on Professional Divisions, this year's program will be arranged with a minimum of simultaneous technical sessions so that members whose interests are in many subjects will find it less difficult to avoid conflicts in their personal schedules. In order to accomplish this desirable objective, recourse is being had to two evening sessions, scheduled for Monday and Thursday, and to an increased number of gatherings, some combined with luncheons, at which the panel method will permit discussion of present trends and topics of interest in general and special fields.

It is expected that the evening sessions will provide an opportunity for the attendance of younger men whose duties make difficult their participation in sessions held during working hours. One of the two evening sessions to be conducted on Monday, November 30, will be devoted to a paper on the "Steamotive," a complete steam-generating unit, its development, and test. The paper describing this new device has been prepared by E. G. Bailey, of the Babcock & Wilcox Co., A. R. Smith, of the General Electric Company, and P. S. Dickey, of the Bailey Meter Company.

The other session on Monday evening will consist of a symposium on the latest developments in time and motion study and is being organized by Prof. D. B. Porter, of New York University.

Turbine History Featured

On Thursday evening one of the sessions will be given over to the presentation of three papers dealing with the early history in this country of the steam turbine. Three papers will be devoted to the Westinghouse, the Allis-Chalmers, and the General Electric turbines, and will be presented by E. E. Keller and Francis Hodgkinson, A. G. Christie, and A. R. Smith, respectively. These papers are the result of a desire on the part of engineers to preserve in permanent record the history of significant engineering developments in this country while the engineers who were associated with them and have had a personal knowledge of details can set them down. It will be recalled that the Founder Societies are engaged in setting up a joint committee to develop such papers and preserve historical records. Professor Christie installed the first Allis-Chalmers turbine. Mr. Keller visited England at the request of George Westinghouse and negotiated the licensing of the Westinghouse Company as manufacturers of the Parsons-type turbine in this country. Mr. Hodgkinson came to this country with the Parsons turbine purchased at that time by Mr. Westinghouse and has been intimately associated with the Westinghouse turbine in this country since that time. Mr. Smith has drawn upon the records of the engineers who developed the Curtis turbine in this country for the General Electric Company. The comprehensive historical review of turbine development afforded by these three papers is an event of national importance in stimulating the preservation of records that would otherwise be too easily forgotten.

Simultaneously with the symposium on turbine history, the concluding session on corrosion-resisting metals, a feature of the Annual Meeting, is scheduled.

Papers on Corrosion-Resisting Metals

In addition to the evening session already noted, two daytime technical sessions in a symposium on corrosion-resisting metals have been arranged for Thursday morning and afternoon.

The information presented is to be in compact form, of a practical nature, free from lengthy theoretical discussions but still sufficiently complete so that when the different papers are assembled they will form a handy reference for the engineer of the subject of corrosion-resistant metals.

The need for such a symposium was expressed by designing and operating engineers of the country who are constantly confronted with many problems on corrosion. They are busy men and not many of them have been able to follow closely the rapid development of this type of information during the past few years. Several of the professional divisions of the Society joined in developing the symposium. Mr. T. H. Wickenden, past-chairman of the Society's Iron and Steel Division, was appointed chairman of the Committee that is arranging the symposium.

Several methods of presentation had been considered to present the material but the most feasible appeared to be according to the different base metals.

The papers which are to be presented are as follows:

Introduction to Corrosion-Resisting Metals, by Dr. F. N. Speller, National Tube Co., Pittsburgh, Pa.

Alloys of Aluminum, by E. H. Dix, Jr., Aluminum Company of America, New Kensington, Pa.

Nickel and Nickel-base Alloys, by F. L. LaQue, The International Nickel Co., Inc., New York, N. Y.

Zinc in the Chemical Industries, by E. A. Anderson, The New Jersey Zinc Company, Palmerton, Pa.

Lead, by G. O. Hiers, National Lead Company, Brooklyn, N. Y.

Cast Iron in Chemical Equipment, by Dr. H. L. Maxwell, E. I. du Pont de Nemours Co. Inc., Wilmington, Del.

Copper and Copper-base Alloys, by R. A. Wilkins, Revere Copper and Brass, Inc., Rome, N. Y.

Corrosion-Resistant Steel (stainless type), by J. H. Critchett, Union Carbide and Carbon Research Laboratories, Inc., New York, N. Y.

So generally useful and significant are the

A.S.M.E. Calendar

of Coming Meetings

October 22–23
Welding Practice Symposium, Cleveland, Ohio

November 30–December 4
Annnal Meeting, New York, N. Y.

papers considered to be that the December issue of MECHANICAL ENGINEERING is to be devoted to them.

The Committee in charge of the symposium drew up the following outline as a guide to the authors:

(1) Typical compositions (tabulated).
(2) Mechanical properties (tabulated).
(3) Available commercial forms, giving general information on whether the material is available in hot- and cold-rolled sheets, strips, bars, extruded, castings, forgings, etc., and some idea of the limiting sizes and gages.
(4) Corrosive conditions for which the material is recommended as well as those for which it is not recommended. This information is to be presented as far as possible by means of tables, charts, or other means to present it in a condensed form. The following is a list of topics to be covered as far as information is available, giving some idea of its suitability, durability, and range of rates of corrosion: Atmosphere, fresh water, salt water, neutral salts, mineral acids, oxidizing acids, organic acids, acid salts, alkaline salts, oxidizing acid salts, oxidizing alkaline salts, and dry gases.
(5) Information should be offered on recommended methods of fabrication, design, forming, joining, machining, etc.
(6) Typical examples of application in construction.

Panel Discussions of Current Topics

Among the discussions planned, to be conducted by the panel method, already mentioned, will be one in honor of George Westinghouse, to be held Wednesday afternoon, at which many former associates of this great American engineer and inventor will speak. Another, under the joint auspices of the Management Division of the Society and the Society for Promotion of Management will be devoted to the subject of human relations. Following it is scheduled a symposium on the subject of training skilled workers in which the Management Division, the Committee on Education and Training for the Industries, and the Society for the Promotion of Management will participate.

Discussers at Luncheon Meetings

An increased number of luncheon meetings at which papers will be presented and topics of immediate interest will be discussed are being planned. These will include luncheons by the sugar group of the Process Industries Division, another by the industrial-power group of the Power Division, one devoted to maintenance, one to textiles, and one to distribution.

Technical Sessions of the Divisions

Technical sessions of the Society's professional divisions will make up the bulk of the daytime program. Among the topics discussed and not already mentioned are: Aerodynamics, fuels, applied mechanics, boiler feedwater, heat transfer, safety, cinder catchers, fluid meters, railroad engineering, thermodynamics, power, cutting of metals, textile drying, Diesel engines, steam turbines, control instruments for steam turbines, mechanical and rubber springs, quieting of machinery, with a demonstration lecture, bearings, layout and equipment of plants, hydraulics, and the cleaning of coal.

The technical program is still in tentative form, and whether or not the wealth of material available can be fitted into the limitations of time and meeting rooms remains to be determined.

General and Social Events

As usual, the annual meeting opens with a meeting of the Council, to be followed by the annual Business Meeting of the Society.

Tuesday evening is Honors Night, at which the awarding of prizes, medals, and honorary memberships will be featured. It will also include exercises appropriate to the 90th anniversary of the birth of George Westinghouse, who was an honorary member of The American Society of Mechanical Engineers and served as its president in 1910.

At the Annual Dinner on Wednesday evening, members of the Society will meet in a brilliant gathering for which many pleasant features are being planned.

On Friday evening the Society will participate in a dinner with the Institute of Aeronautical Sciences, at which the Guggenheim Medal will be awarded to George W. Lewis, director of Aeronautical Research, National Advisory Committee for Aeronautics.

The usual program for women in attendance at the meeting is being formulated, and excursions and committee meetings are being planned.

Special conferences and a luncheon with the Council for student delegates and honorary chairmen of Student Branches are being planned. Details of these events, and a complete program of the meeting, will be featured in the November issue of MECHANICAL ENGINEERING.

Local Sections Delegates Conference

Following the plan in operation during recent years a Conference of Local Sections Delegates will be held in connection with the A.S.M.E. Annual Meeting. Here will be discussed topics that have been whipped into shape at the seven group conferences that are being held in October and November. By this means questions of Society policy and operation are given fullest discussion, and resolutions are formulated for presentation to the Council Meeting on Friday.

Twelfth National Exposition of Power and Mechanical Engineering

To Be Held in New York, N. Y., Nov. 30–Dec. 5

THE Twelfth National Exposition of Power and Mechanical Engineering will be held at Grand Central Palace, New York, November 30 to December 5, 1936. Displays designed to give the visitor the maximum information in the shortest possible time will present new developments in the field of power generation and mechanical-engineering equipment.

Plant accessories are this year well represented by interesting new materials and machines. An exhibitor of turbocompressors and industrial cleaning machines will feature the prevention of dust hazards in factories and foundries. New industrial vacuum cleaners are offered as a preventive for silicosis caused by dust in the lungs of workers. In the same field an exhibitor will offer a variety of new attachments said to solve for the first time many difficult cleaning problems hitherto unsolved by portable vacuum equipment.

Hydraulic-lift trucks for heavy loads will feature shockless lowering of load and the so-called "inching" lift for operation in close quarters. Other exhibits will feature electric industrial trucks, tractors, trailers, hand-lift trucks, chain hoists, and electric trolleys. One manufacturer of industrial trucks eliminates the need for a hydraulic release check in load lowering. In another section of this exhibit a display of portable elevators, electrically operated, will feature a ball-bearing hoist and cut spur gears totally enclosed and running in oil, also a direct-connected motor which eliminates the need for chains or belts.

Mechanical packings will be represented by many materials including asbestos. One exhibitor will call attention to a new semipermanent lubricant which will not dry out, harden, or wash away. This lubricant is said to be impervious to most acids and can be impregnated into braided packings.

Belt fasteners will be featured in terms of strength tests and safety qualities. Recooling sprays, air-washing sprays, and industrial oil nozzles will be on exhibition. In separate sections of the Exposition furnace draft controllers and hydraulic controllers will be featured. The hack-saw people will demonstrate high-speed production cut-off work. On display will be what is claimed to be the fastest, most accurately cutting hack-saw machine.

Production machinery of interest to metal and wood-working plants, will include abrasive belt surfacing machines, belt and wheel grinding and polishing machines, cylindrical

and flat sanding machines. Pumping equipment will offer exclusive and unusual features from the standpoint of operating efficiency and economy. Compressors are featured for the delivery of clean air, free from dust, heat or oil, a factor of importance in industrial chemical and process applications.

Publications and professional societies related to the field of mechanical engineering and power generation and distribution will be well represented.

It is planned to present graphically the latest market information in the power field, showing data on the number of power plants and the current buying characteristics, indicating the current trends beyond the figures of the most recent census. Additional graphic data will be designed to show fundamental services in the province of power engineers, related to the products necessary to perform these services.

The Twelfth National Exposition of Power and Mechanical Engineering is as heretofore under the management of the International Exposition Company, Grand Central Palace, New York. Charles F. Roth is again in charge.

Local-Sections Committee Discusses Society Problems at Dallas

MEMBERS of the Committee on Local Sections of The American Society of Mechanical Engineers met for a discussion of committee and Society problems in Dallas, Texas, June 15, in connection with the recent Semi-Annual meeting. Points in the discussions which are of general interest to all members of the Society are as follows:

Section Reorganization

Dean Woolrich reported on the recent reorganization meeting of the Local Section at Memphis, Tenn., which he addressed. In view of the apparently successful reorganization efforts it was suggested that a similar procedure be followed in the cases of the Chattanooga and Houston sections.

Society Development

Much time was devoted to a discussion of the duties and functions of the committee in general and specifically to its responsibilities in Society development and increase in membership.

1936 Group Conferences

The following dates and locations for the 1936 group conferences which precede the Annual Meeting of the Society and at which matters of Society policy are discussed were announced:

Group I, New London, Conn., Oct. 31–Nov. 1
Group II, New York, N. Y., Oct. 22
Group III, Ithaca, N. Y., Oct. 31–Nov. 1.
Group IV, Savannah, Ga., Oct. 16–17
Group V, Columbus, Ohio, Oct. 16–17
Group VI, Kansas City, Mo., Oct. 24–25
Group VII, Seattle, Wash., Oct. 3–4

With the Student Branches

A New Program

WITH THIS issue the *Student Branch Bulletin* becomes a part of the new and enlarged "News" section of MECHANICAL ENGINEERING.

In recent years the lack of a medium for the dissemination of Society news has been keenly felt. Older members have missed the old *A.S.M.E. News;* while juniors have been anxious to read of the activities of the junior groups now found in all parts of the country. This need has been recognized for several years but until this year the means of satisfying it have been lacking. The solution now advanced is simply this: Substitute for the section "Whats Going On" which has been appearing regularly in MECHANICAL ENGINEERING, a news section, larger and with a new format. In this news section it is planned to cover the business of the Society, the local sections, and the junior groups.

It is a token of the increasing closeness of the tie between the student membership and the Society, that the natural corollary to this solution was to include the material formerly published in the *Student Branch Bulletin*. It is, we feel, a step forward. Inclusion of student news will bring to the attention of the membership the activities and accomplishments of the student members, thus enhancing the prestige and improving the status of the student member.

LOUIS N. ROWLEY, JR.[1]

Branch Meetings

THE ONE hundred and fifteen Student Branches of The American Society of Mechanical Engineers will start functioning anew within the next few weeks. Following is an incomplete list of newly elected student officers who are already planning bigger and better meetings, interesting laboratory experiments, visits to various plants, and a few social gatherings, such as smokers with coffee and doughnuts.....DETROIT, R. John Moore, Edmund Nolan, Robert Proctor, and John Perini.....DUKE, Stanley Boyce, Richard Keane, Robert Martin, and George Bynum.....FLORIDA, W. H. Toske, A. F. Major, Charles Mason, and W. H. Harrell.....GEORGE WASHINGTON, Charles Mikuszewski, Edward Newell, and Ross Strout.....LOUISIANA STATE, Ferd Kramer, Robert Tucker, and L. T. Weathers.....MICHIGAN, John Ingold, Robert Young, Edward Sinclair, and Clarence Green.....NEVADA, Guy Morris, Eugene Rollins, and Vernon Scott.....N.Y.U. (Evening Division), Adolph Panitz, Milton Berg, John Darlington, Edward Roberts, and Oliver Cote.....NORTH CAROLINA, W. Kephart, J. S. Francis, and H. Robbins.....OHIO STATE, Philip Haywood, Eugene McPherson, John Eagle, and Clarence Hall.....ROSE POLYTECHNIC, Clyde Cromwell, Aldin Foley, Frank Blount, and John Sonnefield.....UNIVERSITY OF SOUTHERN CALIFORNIA, Rod Keenan, Richard Esselman, and Elmer Salomonson.....STANFORD, Stuart Weaver, Thomas Macomber, Harold Munton, and Clarence Studey.....TENNESSEE, R. M. Russell, D. F. Kivitt, and C. K. Norris.....TULANE, H. W. Blakeslee, D. E. Jahncke, R. B. James, and P. R. Roehme.....WASHINGTON STATE, E. Engstrom, J. Bratton, and A. McMeekin.....WORCESTER POLYTECHNIC, A. H. Johnson, J. F. Swartwout, D. K. Merrill, and W. G. Richards.

* * * *

Some schools have Engineering Councils to which representatives from the various engineering societies are elected. The following members will represent the A.S.M.E. in their respective schools: FLORIDA, E. B. Knight and R. D. Keller.....GEORGE WASHINGTON, Louis Reznek.....MICHIGAN, John Young.

* * * *

Last semester, PUERTO RICO Student Branch made a five-days' trip around their island visiting sugar factories, foundries, hydroelectric power plants, etc.....RHODE ISLAND had six regular meetings and eight joint meetings with other engineering societies' student branches last year.....At COLUMBIA regular bimonthly meetings are planned for this term at which each member will be given the opportunity to speak on a subject of his own selection. Occasionally, motion pictures of an engineering nature will be shown to the members.

* * * *

Each spring, the members of the Student Branch at STANFORD are given the task of making in the school's foundry and shops a brass plate approximately 1 inch thick and 30 inches square with the senior-class year numerals inlaid with babbitt. On commencement day, the class lays the plate as a memento in the sidewalk of the Inner Quadrangle.

* * * *

The report from NORTH CAROLINA says that K. D. Osborn has been elected corresponding editor. His duty will be to supply us with news and interesting topics from his Student Branch. Now, if the rest of the Branches do likewise, the task of writing these Student Meeting notes will be a pleasure. It wouldn't be necessary then to try and get something of an interesting nature from routine secretaries' reports such as the following: "Meeting opened at 7:30. Motion to make reservations at hotel for Conference. Carried. Secretary to take care of this. Motion made that Mechanicals invite Electricals to next feed. Motion carried. Meeting closed."

LESLIE F. ZSUFFA.[2]

[1] Chairman, Editorial Board, *Student Branch Bulletin*, Jun. A.S.M.E.

[2] Member of Editorial Board, *Student Branch Bulletin*. Jun. A.S.M.E.

Michigan Mining-Tech Holds 50th Anniversary

WITH THE inauguration of President Grover C. Dillman as its special feature, the Michigan College of Mining and Technology's 50th anniversary and alumni reunion at Houghton on August 5, 6, and 7 drew many hundreds of former students and honor guests; many attending as official delegates from colleges, universities, and societies.

This was the first of the six five-yearly reunions in which a large number of mechanical-engineering alumni took part. Degrees in fields other than mining and metallurgy were authorized in 1927, but only a relatively few men were graduated in mechanical, civil, electrical, and chemical engineering and in chemistry and geology prior to the 1931 reunion. This year, however, many of the nearly 600 nonminers and nonmetallurgists among Michigan Tech's 3000 living former students were present.

The college was founded as the Michigan Mining School in 1886. Eleven years later it became the Michigan College of Mines. Expansion of curriculum and change of name were voted by the state legislature nine years ago in view of the preeminence won by many graduates in fields other than mining and because ninety per cent of the college work did not pertain directly to mining.

The George Hillyer, Jr., Group IV Award

AT THE first A.S.M.E. Student Branch Conference held at Chattanooga, Tenn., in April, 1932, the George Hillyer, Jr. Award of fifty dollars was given by Mrs. Hillyer in memory of her husband, for many years a member of the Society.

This award was for the best paper presented by a student from any of the branches taking part in the Group IV Conference. It was won that year by J. C. Whitehouse for his paper on "Practical Economics, a Necessity for the Engineer."

Mrs. Hillyer has most generously renewed the gift each year since then, and the Society is grateful to her for her continued interest.

The award was presented this year at the Group IV meeting at Birmingham, Ala., April 6, to Hobert W. Blakeslee of Tulane University for his paper entitled, "Binary Mercury-Vapor-Steam Cycle Applied to Power Generation."

Why Not Read "Mechanical Engineering?"

It Covers a Wide Variety of Interesting and Useful Subject Matter

ONE OF the reasons for incorporating the *Student Branch Bulletin* with the A.S.M.E. News was the hope that student members of the Society would thereby get to know MECHANICAL ENGINEERING better. So why not make a start with this issue and contract a useful habit?

To give an idea what this issue contains we offer a few comments on the major articles. In addition to these articles there are editorials, letters from readers, abstracts of important articles in other magazines, book reviews, and the A.S.M.E. News, telling what the Society is doing. And don't forget the advertisements. It is not too early to begin to know the firms that supply mechanical-engineering equipment and the latest they have to offer.

Who Was Coulomb?

Dave Kreider used to look expectantly at a particularly sleepy Yale freshman in his physics class and assail him in an inquisitorial tone with, "Watt is a unit of power," to which the student would reply feebly, "I don't know," amid cheers and guffaws. Most engineers could probably answer more intelligently the question, "What is a coulomb?" than they could, "Who was Coulomb?" Professor Hollister gives the answer to this second question in this month's leading article. And the surprises are great to almost every one. For Coulomb was one of those early scientists who discovered a great many fundamentals of mechanics found in textbooks. After reading this brief biographical essay you can spring one on your professor of industrial management by asking him if he knew that Coulomb made studies of the "one best way to work" several generations before Frank Gilbreth coined that phrase.

Modern Varnishes

Every one has heard how Kettering eliminated the neck in the bottle of automobile manufacture by applying lacquer instead of the numerous coats of slow-drying enamels and varnishes formerly used in painting automobiles. It gave a tremendous fillip to the paint and varnish industry and changed the technique of finishing wood and metal. Chemical engineers have developed a variety of synthetic resins for such purposes. In a paper that was presented at the Niagara Falls meeting of the Society and to be found on pages 621–624 of this issue, Robert J. Moore gives a brief account of the history of these developments and brings them down to the present.

What Is the Reynolds Number?

There are certain concepts in engineering that seem simple enough when intelligently explained, but unless an engineer uses them frequently he is likely to forget about them and wonder vaguely what it's all about when he comes across them in his reading. Such a concept is the Reynolds number, useful in the growing applications of aerodynamics and hydraulics, which Professor Bakhmeteff explains quite simply in this issue, pages 625 to 630. It is not a bad idea to salt this expository article away for future reference, and it may give a different slant to subjects you are now studying. You cannot be too familiar with fundamental concepts like this.

Planning

This much used and, to some, overworked word is in the heyday of its popularity. On pages 631 to 634 Professor Rautenstrauch goes back of popular usages and develops an interesting line of thought which will appeal to the orderly minds of engineers. It will give you something to think about and would make a grand basis for a lively discussion at a Branch meeting, especially if you invite some arts men who know all about political economy.

Warning

If you have a friend who thinks he can get a job at good pay by taking a correspondence course in Diesel engineering, give him Professor Hechler's article on Diesel-engineering education, pages 635 to 637 of this issue, not with the idea of discouraging him but so that he may go into it with his eyes open. He will appreciate your interest in his welfare.

Giving a Million Dollars

As in making rabbit stew, first get your million, but there's more to it than that. For if you are going to do the right thing by your alma mater you will take Professor Ennis' advice and make it $1,700,000. Turn to page 638 and see why. If your college president doesn't know this little catch about endowments you had better rush right over and tell him. He should thank you for the tip.

Spraying

Put this down for future use when you are tempted to throw away a worn shaft or pump rod. L. E. Kunkler, on pages 639 and 640, tells how metal is sprayed on metal parts in making maintenance repairs to worn machinery. A surprising number of practical applications of metal spraying have been developed, with worth-while savings in expense.

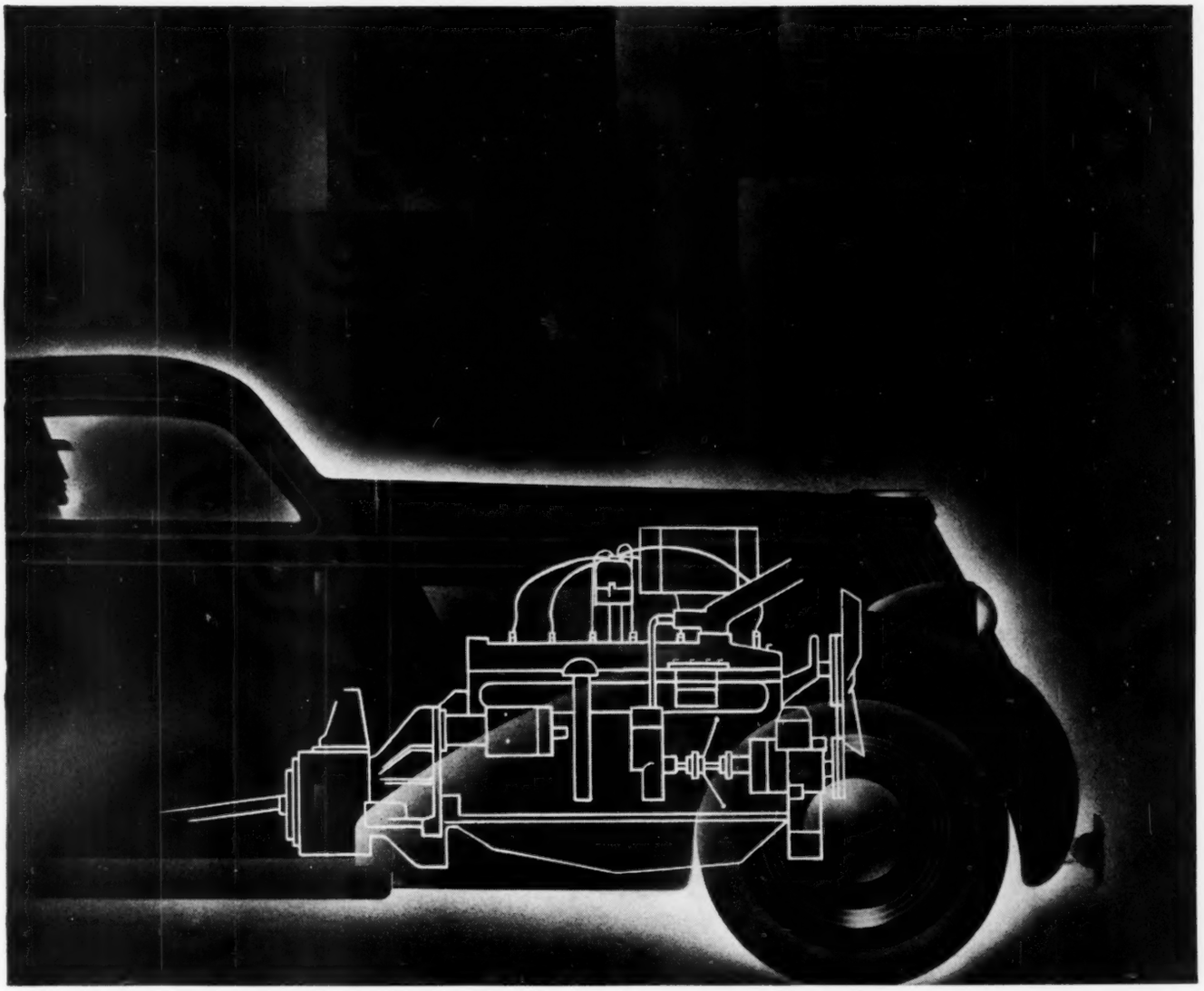
More Than You'll Make Next Year

Unless you are better than the average, you are not likely to make $2500 the first years out of college. Yet this is the income that Mordecai Ezekiel thinks the average American might have if we knew how to run our national economy properly. He has written a book about it which Professor Shute reviews in this issue, giving his own views on the economist's ideas. You'll like the review, which is one of a series published every month.

Real Brain Food

You can't take up a book on the properties of steam without finding Max Jakob's name in it. In three lectures on evaporation, pages 643 to 660 of this issue, Doctor Jakob puts into English the results of his many years of research on this subject. He tells a fascinating story about bubbles and heat transfer, and if you take any advance work in thermodynamics, you may find that these lectures will be required reading for it. Better cut them out and save them. They may come in handy some day when you are given a job involving heat transfer. Next month's lectures will be on condensation. Evaporation and condensation are common phenomena but few persons understand them. Doctor Jakob makes it all quite clear.

(*A.S.M.E. News continued on page 678*)



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Other Engineering Activities

F. D. Wilson to Address Smoke-Abatement Group

F. D. WILSON, of the Babcock & Wilcox Company, New York City, will be the principal speaker at the first regular meeting of the newly organized Industrial Smoke Abatement Association of Hudson County, New Jersey. Mr. Wilson will speak on the subject; "Modern Boilers and Refractories." Announcement of the program for the year 1936–1937 has just been made by William G. Christy (Mem. A.S.M.E.), Smoke Abatement Engineer of Hudson County, New Jersey.

The Industrial Smoke Abatement Association of Hudson County was organized a few months ago by representatives of 300 industries having plants located in Hudson County, which lies just across the Hudson River from New York City. A. W. Akins, of the Standard Oil Co., of New Jersey, is president of the Association. Harry Yunker, of the Jersey City Printing Company, is secretary, and John Gerhard, of Swift and Company, is treasurer.

Regular meetings of the Association will be held every sixty days beginning in September, at Stevens Institute of Technology, Hoboken, New Jersey.

A.S.M.E. Invited to A.S.C.E. Meeting at Pittsburgh

MEMBERS of The American Society of Mechanical Engineers have been cordially invited to attend sessions of interest to them at the forthcoming fall meeting of the American Society of Civil Engineers, to be held in Pittsburgh, Pa., at the William Penn Hotel, October 13 to 17.

Following two of the four sessions of a symposium on flood control with which the meeting opens on Tuesday, a group of papers on the economic aspects of energy generation will be presented on Wednesday. The subjects to be discussed are: Thermogeneration of energy, hydrogeneration of energy, improvements in utilization of energy, cost of generation of energy, and economic aspects of energy generation. Members of the A.S.M.E. whose interests lie in the field of power generation and economics will find this session instructive and stimulating.

Another feature of the program of interest to mechanical engineers will be a four-session symposium on structural applications of steel and light-weight alloys. These sessions will be held on Wednesday and Thursday morning and afternoon. The following subjects will comprise the program: Modern stress theories, tests of engineering structures and models, photoelastic determination of stress, metallurgical and manufacturing aspects of structural low-alloy and high-alloy steels, corrosion in relation to structures and structural materials, actual applications of special structural steels, the field of high-strength steels in structural engineering, application of stainless steel in light-weight construction, structural application of aluminum alloys, and magnesium alloys and their structural application.

In addition to the technical sessions already mentioned others will be devoted to problems in planning major highways, modern highway design and construction, and stream pollution. Social events and excursions to points of engineering interest in and around Pittsburgh are also being planned.

The invitation to A.S.M.E. members to attend the technical sessions of interest to them, which comes from the national headquarters of the American Society of Civil Engineers and from the Pittsburgh group, is an example of a growing tendency on the part of engineering societies to afford reciprocal courtesies greatly appreciated by their officers and individual members.

Institute of Physics to Hold Anniversary Meeting

A JOINT meeting of the founder societies of the American Institute of Physics will be held in New York on October 29 to 31, 1936, at the time of its fifth anniversary. This meeting will consist partly of the regular papers of the separate societies and partly of sessions in which all of the societies will participate. The founder societies of the Institute are the American Physical Society, the Optical Society of America, the Acoustical Society of America, the Society of Rheology, and the American Association of Physics Teachers.

Leaders in various fields have been invited to take part in symposia concerned with the training of physicists for industry and with the application of physics in industry. While abounding in technical value, these symposia will be addressed to all who are interested in sicence whether or not they are specialists in the fields discussed. Every effort is being made to arrange a program of exceptional interest. Nonscientists as well as engineers and chemists are cordially invited to attend this meeting.

Headquarters will be at the Hotel Pennsylvania.

Lectures on Industrial Standardization

THE engineering and management aspects of Industrial Standardization will be discussed in eight lectures by Dr. John Gaillard, industrial engineer, a member of The American Society of Mechanical Engineers and the Society for the Advancement of Management, each Wednesday evening, October 7 to November 25, inclusive, in the auditorium, Metal Products Exhibits, Inc., Rockefeller Center, New York, N. Y. Each lecture, lasting one hour and a quarter, will be illustrated with lantern slides and will be followed by 30 minutes of general discussion on the subject of the evening.

The subscription fee, $12 for the general public, is $10 for members of Engineering Societies and students registered at engineering colleges.

Members of engineering societies are invited to attend the first lecture, complimentary tickets for which will be sent upon application to Room 807, 29 West 39th Street.

Western Society Sponsors Graduates Courses for Engineers

ENGINEERS in Chicago and vicinity, through the efforts of the Western Society of Engineers in cooperation with local engineering schools, will be offered a part-time program of graduate study beginning in September, 1936.

The Board of Direction of the Western Society of Engineers has approved the committee's recommendation that the Society work with the local colleges and universities in developing post-graduate work for employed engineers, and detailed plans are being prepared in order that the program will be well under way by the middle of September.

According to the survey, there are approximately 8000 graduate engineers and architects under 35 years of age in the Chicago area; and, with the increasing importance of advanced study in all technical fields, it seems particularly appropriate that the Western Society of Engineers should encourage these men to continue their education on a part-time basis.

The program of study will be so set up that a well-integrated sequence of work will be provided leading to the degree of Master of Science in several branches of engineering.

Steel Engineers Association Changes Name

IT WAS announced at the regular monthly meeting of the Directors of the Association of Iron and Steel Electrical Engineers held June 23, that, effective August 1, the name of the Association would be changed to Association of Iron and Steel Engineers.

A.M.A. to Hold Conference in New York, Oct. 21–22

THE office management division of the American Management Association will hold its annual conference at the Hotel Commodore, New York City, October 21 and 22. Alvin E. Dodd, A.M.A. president, recently announced.

The conference will discuss the problems faced by those in charge of office work as a

(*A.S.M.E. News continued on page 680*)

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result of the depression years and of recovery. There will be described experiences of progressive companies in restarting essential office-management activities that had been curtailed or suspended. Recent progress will be appraised; future developments forecast.

W. R. Woolrich Appointed Dean of Engineering, at University of Texas

ANNOUNCEMENT has been made of the appointment of W. R. Woolrich, member, A.S.M.E., formerly director of Agricultural Industries Division, Tennessee Valley Authority, and professor of mechanical engineering, University of Tennessee, as dean of the College of Engineering, University of Texas, Austin, Texas.

News From Washington

By American Engineering Council

BEHIND the scenes in Washington, there is emerging on the part of those in the employ of various old and new divisions of the government and on the part of those in charge of administrative responsibility, a clearer understanding of two fundamental truths. The first is that the wide-flung government organization which has been set up under many of the New Deal agencies must be reassembled and consolidated. Not only is this desirable from the point of view of political expediency but it is rapidly becoming evident that only a complete reorganization will eliminate the waste and inefficiency which have grown up with scores of emergency proposals and organizations which have been undertaken. The second broad fact is that in such agencies as the PWA, WPA, and National Resources Committee, the blunt facts of engineering truth are persuading those who have been guiding the expenditure of government appropriations that several of the proposals are impossible of accomplishment. There are, of course, many currents of thought in this whole situation but it is fair to say that the kind of thinking that engineers stand for is coming to be looked upon as essential.

No matter who is President, those in Washington who are responsible for policy and those who are in the organization carrying out policy, know that fundamental changes must be made, if the money is to be spent effectively by the federal government for such projects as flood-control, relief, public construction of all kinds, and the many government projects involving the conservation of natural resources.

Up to the present time, the desire for quick action and the attainment of widely publicized emergency objectives has led to the development of projects and of organizations to carry out those projects, in which there has been too much opinion and too few facts. It is now evident on the basis of the various surveys that have been conducted (almost as a side issue of the emergency objectives), that the facts so developed will influence methods and objectives as they have not done before. Speaking in engineering language the procedure must be first to find what the facts are and then to develop plans and put into execution projects which are based on these facts. Reflections of this are seen in the abandonment of certain of the activities of the Resettlement Administration, in the reshaping of the policies of the Rural Electrification Administration and in the moves by Secretary Ickes to associate conservation and public works into one single division of the government.

Candidates for A.S.M.E. Membership

THE application of each of the candidates listed below is to be voted on after October 26, 1936, provided no objection thereto is made before that date, and provided satisfactory replies have been received from the required number of references. Any member having comments or objections should write to the secretary of the A.S.M.E. at once.

NEW APPLICATIONS

ALLAN, GEO. W., Brooklyn, N. Y.
ARCHER, W. HARRY, San Francisco, Calif.
BECKWITH, OLIVER P., Yonkers, N. Y.
BORN, MAYNARD R., San Francisco, Calif. (Re)
BROWN, T. C., Ashland, Ky.
BROWNSCOMBE, PHILIP J., East Orange, N. J.
BUSS, C. A., Bridgeport, Conn.
CONNOLLY, JAS. J., Pawtucket, R. I.
CORBIN, C. M. L., JR., Woodlyn, Pa.
GOLDSBURY, JOHN, Lynn, Mass.
HAWKINS, ALBERT E., Wood Ridge, N. J.
KENNEY, RAYMOND A., Waban, Mass.
KENTIS, GEO. E., JR., Cleveland, Ohio
LAUSCHE, LUVERNE F., Madison, Wis. (Re)
LINEBAUGH, JOHN E., Hendon, England
MALCOLM, R. M., Toronto, Ont., Canada
MCLELLAN, EDW. A., New Orleans, La.
MCWANE, GEROULD R., Sandusky, Ohio
MONTIN, J. R. T., Alameda, Calif.
MORTON, BYRON B., New York, N. Y.
NULLE, J. HOWARD, New York, N. Y.
PEARSON, HARRY F., Guatanamo, Cuba
PERLEY, J. DWIGHT, Hartford, Conn.
SAMOILOFF, LEON A., Philadelphia, Pa.
SCHRADER, THOS. O., JR., Pittsburgh, Pa. (Rt & T)
SUNNEN, JOSEPH, St. Louis, Mo.
VIERCK, ROBERT K., Denver, Colo.
WEBER ARTHUR, Corning, N. Y. (Re)
WISE, ROY T., New York, N. Y.

CHANGE OF GRADING

Transfers from Junior

BARNARD, NILES H., Lincoln, Nebr.
BENZIEN, FRITZ E., Bayonne, N. J.
BISCHOFF, ROBERT, York, Pa.
CLARK, DONALD S., Pasadena, Calif.
DEAN, FRANCIS FURMAN, Kingsport, Tenn.
DE BAUFRE, WM. L., Lincoln, Nebr.
DEWEY, WM. V., Chicago, Ill.
FISCHER, KERMIT K., Wyncote, Pa.
GUINAN, JOHN F., Brooklyn, N. Y.
HANSEN, HANS I., Milwaukee, Wis.
KING, WILLIAMS V., Brooklyn, N. Y.
MCQUISTON, W. BRYCE, Pittsburgh, Pa.
PETRESCU, OVID S., Madison, Tenn.
ROCKEFELLER, H. E., New York, N. Y.
RODNITE, JOHN J., Boston, Mass.
SAUCIER, J. HENRY, JR., Dallas, Tex.
SEIB, WM. A., Akron, Ohio
TAYLOR, MORRIS P., Stanford University, Calif.
TELFORD, M. H., Bronxville, N. Y.
WEINER, L. P., Peoria, Ill.
WELCKER, WM. AUGUST, JR., Columbus, Ohio

Necrology

THE following deaths of members have recently been reported to the Office of the Society:

CAMPBELL, THOMAS J., August 19, 1936
HUNICKE, C. CAMPBELL, May 22, 1936
KILLGORE, EDWIN R., August 1, 1936
LARKIN, WILLIAM H., JR., July 16, 1936
MCCANDLESS, JOSEPH H., January 18, 1936
PATTISON, HUGH, August 20, 1936
SEABURY, GEORGE E., July 13, 1936
WALLACE, JOSEPH H., July 7, 1936
WESTON, EDWARD, August 20, 1936
WILES, HENRY R., June 27, 1936

Members and Local Section officers are urged to notify the Society promptly of deaths and to supply newspaper clippings and other biographical material for memorial notices.

A.S.M.E. Transactions for September, 1936

THE September, 1936, issue of the Transactions of the A.S.M.E., the *Journal of Applied Mechanics*, contains the following papers:

TECHNICAL PAPERS

Analysis of Plate Examples by Difference Methods and the Superposition Principle, by D. L. Holl

Increasing the Fatigue Strength of Press-Fitted Axle Assemblies by Surface Rolling, by O. J. Horger and J. L. Maulbetsch

The Behavior of a Brittle Material at Failure, by M. M. Frocht

RESEARCH REVIEW

Review of Recent Research Work in Plasticity, by A. Nádai

DESIGN DATA

Stresses in Pressure Vessels, by J. L. Maulbetsch and M. Hetenyi

DISCUSSION

On previously published papers by R. Baudry and L. M. Tichvinsky; and A. V. de Forest

BOOK REVIEWS

By J. N. Goodier; J. C. Hunsaker; C. H. Jennings; and E. E. Sechler